REPEATABILITY OF PERFORMANCE RANKINGS AND WOOL PRODUCTION CHARACTERISTICS OF MERINO EWES IN A SEMI-ARID FARMING ENVIRONMENT

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by

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Declaration:

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

Dale A. Manson
Animal Ethics Statement:

This project did not involve any activities which resulted in abnormal stress, pain or injury to the sheep involved.

Approval for the conduct of the project was provided by the University of Adelaide animal ethics committee (Approval # W/79/91) and the South Australian Department of Agriculture animal ethics sub-committee (Approval # 16/92).
ABSTRACT:

A flock of 205 strong wool South Australian bloodline Merino sheep was run in a semi-arid cereal/sheep farming environment at Wanbi in the Murraylands area of South Australia. Shearing and collection of performance records occurred on five separate occasions at successive ages ranging from 6 months to 42 months. Characters examined were body weight, greasy fleece weight, clean fleece weight, mean fibre diameter and eight Woolplan selection indices.

Four key indicators were used to assess the most appropriate age of measurement and selection, in order to provide the best compromise between selection accuracy and minimisation of the period that sheep must be retained until selection is undertaken. These key indicators were; estimated repeatability of each character; phenotypic correlation of character between age of measurement and adult performance; phenotypic correlation of character between adjacent measurement ages; and accuracy of producing ability.

The quality of performance records for within-flock selection remained unaffected by non-genetic between-year variation imposed evenly across the entire flock. Between-year variation was induced by animal age and environmental factors such as season and nutritional status. Provided that non-genetic between-animal variation is excluded and data collection procedures are sound, producers can have a high degree of confidence in the reliability of objective performance measurements collected within their flocks.
Repeatability estimates and phenotypic correlation coefficients from this trial indicated that the South Australian strong wool Merino strain is in the low to medium range in comparison with other Merino strains present in Australia. Performance measurements collected on sheep at the 6 month age did not provide a satisfactory indication (not significant) of relative performance superiority of the animals during later adult life.

However single performance measurements collected at 12 months of age provided a reliable and accurate (P<0.001) indication of later performance for body weight, mean fibre diameter and all Woolplan selection indices apart from the CFW options for indices #1 & #2. A second performance measurement of clean fleece weight, greasy fleece weight and Woolplan CFW indices #1 & #2 at the 18 month age provided an accurate (P<0.001) indication of later adult performance.

Two sheep selection systems are available to producers. The first recommended system is a a two-stage selection procedure involving assessment of the flock at 12 months of age for greasy fleece weight and body weight, followed by culling and a second assessment of the remaining animals for greasy fleece weight and fibre diameter at the 18 month age. The second recommended system involves the once-off use of a selection index, using performance measurements collected at the single measurement age of 12 months. Selection indices suitable for this system are the GFW option for Woolplan indices #1, #2, #3 and #4, and the CFW option for Woolplan indices #3 and #4.
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1. INTRODUCTION:

1.1 Background to the topic:

In addition to the macro economic effects of world wool prices and production costs, continued profitability and sustainability of the Merino sheep industry in Australia relies heavily on an on-going process of genetic improvement. The stud industry is responsible for the provision of most of this genetic improvement, although some minor influence comes from non-stud breeding systems and commercial sheep producers. Selection and breeding policy involving the ram component within these systems is of paramount importance in determining the rate of genetic progress.

As part of the normal management program within Australian stud and commercial Merino sheep flocks, a process of culling and selection occurs at ages ranging from 1 to 18 months. Walkley (1987) reported that in the majority of ram breeding flocks, the ram drop is culled sequentially during the period between lamb marking and the major classing conducted at a later age. During the period prior to the 1970’s, the majority of Merino stud rams were selected at 15-16 months of age with 12 months wool growth. However since then, the stud Merino industry has predominantly adopted a practice of measuring rams at ages less than 12 months and with around 6 months wool growth. A survey conducted by Ponzoni (1980) revealed that in studs using objective measurement, shearing of ram lambs occurred at an average 4 months of age, classing of rams occurred at an average 11 months of age and hogget ram shearing at an average 13 months of age.
1.2 Reasons for investigating the topic:

Ram producers are forced to reach a compromise when determining the most appropriate stage at which their animals are assessed to be culled from, or incorporated into the breeding flock. Assessment at a very early age (ie. six months) significantly reduces the cost of husbandry, particularly on-going expenses associated with feeding the animals. It also permits a more rapid utilisation of the rams. However temporary environmental factors in early life such as maternal influence, birth type and age between individual animals can reduce the reliability of visual appraisal and objective measurements of animals within a selection group assessed at this early age.

Previous work has suggested that delaying the assessment of rams until a later stage (ie. at hogget age of 10 to 18 months) will provide a more accurate indication of lifetime performance of the animals within the selection group. However, the increase in the age of assessment also involves greater husbandry costs and lengthens the period until the animals are available for sale or breeding.

Although the need to utilise objective measures of performance in wool-sheep is generally well recognised by the South Australian Merino industry, a number of problems arise:
- Credibility being given by some commercial and stud Merino breeders to early-age data collected on young sheep with measurements that do not accurately indicate future performance due to the effect of environmental and maternal influence.

- Lack of confidence by breeders of Merino sheep in the value of performance measurements collected according to current industry guidelines (10-12 months of age with 6 months wool), as an accurate indication of the relative lifetime performance of the animals.

- Scarcity of repeatability estimates based on the current industry practice of objectively measuring animals at ages less than 12 months and with around 6 months wool growth.

- Scarcity of repeatability estimates derived from animals of the South Australian strong-wool Merino bloodline.

- Concerns about the ability of selection indices to accurately reflect the true commercial performance of animals.
1.3 Significance to the industry:
Breeders of South Australian type strong-wool Merino sheep have access to very little information relating to the estimated repeatability of production characters of animals run in a typical semi-arid cereal/sheep production zone. This study was conducted to provide repeatability estimates for various wool and body characters measured on sheep of this bloodline. In addition to these repeatability estimates, a number of other key indicators are formulated to guide selection decisions. These indicators are correlation between age of measurement and adult performance, accuracy of producing ability and the correlation between successive measurement ages.

The concerns of breeders are addressed through the provision of soundly based evidence obtained in the local environment and using a representative bloodline. This evaluates the merits of current Merino sheep selection practices that have been jointly developed by the scientific community and leading stud breeders. Recommendations are provided for the determination of the most appropriate age of assessment and selection of rams. The study seeks to identify selection strategies that will enhance Merino enterprise profitability and wool industry sustainability.
2. LITERATURE REVIEW:

2.1 General Background of the Industry:

2.1.1 Merino Studs and Strains

The Australian Merino wool industry is primarily structured in a pyramid manner with a small number of parent studs at the apex, providing the major genetic influences governing the breeding direction of a greater number of multiplier studs and commercial producers located at the broad base of the pyramid structure. The multiplier studs and commercial producers comprise the bulk of the nation's sheep flock. In their study of the Australian Merino stud industry, Short and Carter (1955) noted that the fine wool Merino type contained three parent studs, the medium non-Peppin Merino type contained two parent studs, the medium Peppin Merino type contained seven parent studs, and the South Australian strong wool Merino type had five parent studs.

A study by Roberts et al. (1975) noted that of the original 17 family groups, only 11 remained and two new ones had emerged. They reported that studs supplied up to 125,499 flock rams to the Merino industry. This represented between 50 and 90 percent of the industry's total requirement for flock rams. Their conclusion was that the stud industry was clearly the major supplier, but not the sole supplier, of flock rams.

A report by AACM-Macquarie (1993) estimated that there were 1,600 stud Merino breeders and 400 non-registered Merino breeders including group schemes in
Rogan (1995) reported that the Australian Association of Stud Merino Breeders (1993) estimated that there were 1,879 ram breeders registered with their association in 1992 and that they accounted for the mating of 1.3 million ewes and the sale of 181,700 rams.

The flow of genetic influence in the classic scheme analysed by Short and Carter (1955) is directed downward from one tier to another, without upward movement. In practice a minor amount of genetic material may also flow upward from multiplier and daughter studs to parent studs, and also laterally between producers operating at the lower echelons of the pyramid structure. Turner (1977) broadly classified Merino strains as fine, medium or strong according to quality number, with parent and daughter studs remaining within one fine, medium or strong category. She also said that commercial flocks generally remain within one wool type, although they do sometimes switch from one category to another.

According to Turner and Young (1969), the wool market demanded a wide range of wools, while at the same time also specifying uniformity within each lot offered for sale. They reported that as various Australian strains of Merino had been produced which could meet this demand with wools of high quality, graziers tended to keep to one wool type (fine, medium or strong). Breed or strain crossing was thus not common in Australia, except for meat production. These authors suggested that distinct strains of the Australian Merino have been produced and fall into three main categories.
These are strong-wool with counts of 56s to 60s, medium-wool with counts of 64s and fine wool with counts of 70s and higher.

In a review of the industry, Ponzoni (1995) indicated that rather than remaining a homogeneous breed, the Merino has gradually evolved into a number of distinct populations, suited to different environments and production systems. He recognises seven distinct groups within the Australian Merino. These are Superfine, Fine, Medium, Strong, Poll, Fonthill and Booroola Merino.

Despite the traditional tendency for Merino breeders to remain loyal to the one bloodline, Peart (1990) reported that the new technologies of artificial insemination and embryo transplantation had led to a considerably greater mixing of bloodlines. This was because various bloodlines could be secretly sampled and virtually tested without the loss of social status by actually publicly buying the rams to take home. Banks (1988) reported that choices between flocks as sources of either teams of rams or individual sires, are continually being made in the industry and that this between-stud competition serves as a spur to better breeding efforts.

Kinghorn and Atkins (1987) reviewed the progress of recent Merino strain trials conducted by the Victorian Department of Agriculture at Werribee and Hamilton, and by the New South Wales Department of Agriculture at Trangie. They concluded that Merino strains may be nearly as genetically distinct from one another as are different breeds, reflecting periods of domestic isolation as long as 30 generations.
They indicated that heterosis amongst Merino strains appears to be worth exploiting. This could no doubt lead to an even greater departure by general studs and commercial breeders from the single parent stud hierarchy, to a more general breeding system which utilises a divergence of Merino bloodlines. Banks (1987) believed that in the future, the traditional stud industry hierarchical structure would probably remain largely intact, with modifications being limited to selection practices at the stud level and optimisation of gene transfer rates both up and down the hierarchy.

Studs not only determine the genetic direction of the commercial producer, but as Peart (1979) highlighted, a concept of quality and value is also dictated by the stud. He asserted that many of the present sheep breeders and their fathers were trained as jackeroos on the parent studs. By education and family example, the stud's notion of quality was reinforced and assent was annually renewed at the visit to collect the rams. The reason why the majority of sheep producers prefer to purchase rams from a stud is largely based on a respect for the assessment skills held by the studmaster.

Peart (1979) cited that studs are the authority on and repository of sheep quality. He reported that quality assessment is a visual-tactile skill taught superficially through such systems as the annual show and jackeroo training.
Lax and Jackson (1987) observed that the stud Merino industry commonly utilises objective measurement techniques to select for ram wool production in a single location, with some of the ram progeny then being mated to flock ewes in different locations.

They claim that as flock owners usually retain only ewe and wether offspring for wool production, within the industry, genetic gain in wool production is assessed as ewe and wether wool production at diverse locations.

They also indicate that in the past this has limited the ability of buyers to identify heavy cutting rams and as such has reduced buyer demand. However with the growing availability of objective measurement and selection indices to ram buyers, the demand for above average fleece weight rams has grown. James (1987a) states that given the organisation of sheep breeding, with genetic change being produced primarily by studs who derive their main income from the sale of breeding stock to wool producers, the possibility exists for a conflict of interest between the different levels of the breeding hierarchy. He suggested that while the studs wish to maximise sale of rams, growers want to maximise income from wool and consumers want to buy wool products as cheaply as possible. In his opinion, the conflict arises from the fact that genetic change and the selection of superior stock which may benefit one of these three groups, will not necessarily be of benefit to the others.
This point is also reinforced by Dolling (1970), who noted that while the stud breeder has a greater interest in ram sales than in the stud ewe flocks' wool cut, the commercial breeder is extremely interested in his ewes' wool cuts, while the owner of wethers is overwhelmingly interested in wool cuts.

Ponzoni (1979b) observed that the primary goal of most commercial sheep producers is to maximise monetary returns from their flocks. However as they depend chiefly on stud ram sources for any permanent genetic improvement, it is essential that selection objectives in stud flocks include the traits that influence financial returns in commercial flocks. He is of the opinion that the diverting of selection pressure in studs to traits of no financial importance to the commercial breeder is a waste of genetic resources. These sentiments are shared by Metcalfe and Brien (1992) who reported that stud breeders are not necessarily motivated by the same primary determinants of profit that exist for the commercial wool producer. They indicated that while profit for the ram breeder is determined by what ram buyers demand in the future, many ram breeders are so alienated from the needs of the commercial wool grower that they do not see the client's profit as their primary aim. In essence, ram breeders are not driven by the kilograms of clean wool produced per hectare and the price received for it.
In a study of the NSW stud Merino industry, Savage and McGuirk (1976) reported that while precise estimates were not available as to the percentage of flock rams that the studs provided, a figure as high as 80% was not unrealistic. They acknowledged that it was widely appreciated that in a breed so structured, with a separate ram-breeding stud sector, the long term rate of genetic improvement was determined by the selection and breeding practices of the studs.

Peart (1979) observed that it is the parent stud that sets the fee scale for flock rams purchased during the annual buying visit by commercial producers. The stud classer often plays a key role in maintaining the close business association between flock and stud by assisting in the choice of rams for commercial producers and annually culling the commercial producer's maiden flock ewes. He also observed that the assessment of quality is a professional skill held tightly by the sheep classer, who through classing the maiden ewes and selecting the rams for the flock owner, completely controls genetic progress. Further, he commented that such a stable social organisation controlled by the parent studs and the professional sheep classers is well able to resist change and generally has done so.

Peart (1979) also suggested that the commercial sheep breeder and his peer group are socially tied to the stud and all trust, accept, and practise the stud's notion of quality. The strong association between particular studs and their commercial clients is highlighted by a survey of 145 commercial Merino breeders in South Australia conducted by Greenslade (1989).
When asked if they purchased rams from the same source each year, 65 per cent responded yes and a further 23 percent indicated this was mostly the case.

However in Western Australia, Hamersley (1987) reported that the stud industry is undergoing a period of change. A restructuring of the traditional parent-daughter stud system and a trend to mixing bloodlines to breed a more suitable WA type has taken place. He suggested that a narrowing of the quality gap between larger older studs and smaller newer studs has meant that parent studs often did not hold a quality advantage, the traditional reason for their existence as a parent stud.

He also highlighted the failure by some long established parent and daughter studs to keep pace with changing demand and quality levels as reasons for the shift by breeders. Due to a lack of numbers of parent studs within the Poll Merino industry during the development phase of the breed, there was far more adherence to the development of a type factor rather than to specific bloodlines. This has led to the classification of most poll studs as “general”.

2.1.2 Nucleus and Group Breeding Schemes

Banks (1987) observed that a small proportion of the Merino flock is serviced outside the traditional stud hierarchy, in a smaller number of co-operative groups forming open nucleus breeding systems. Ponzoni (1995) acknowledged that the concept of open nucleus breeding was popularised in the 1970’s.
He reported that there is a flow of genes not only from studs to commercial sheep, but also in the opposite direction. Turner (1977) stated that the general principle is that co-operating flocks contribute superior ewes annually to a central ram breeding nucleus, either directly or through a middle tier of multipliers, and in return have access to rams bred either in the nucleus or the multipliers.

According to James (1987b), the open nucleus breeding system is of most value when reproductive rates are low and selection intensity on the female side is not great. The low selection intensity on the female side means the lag in genetic progress between females in the nucleus and the base flocks is not great, resulting in a greater possibility that there will be base flock females that are genetically superior to some in the nucleus. If these superior females in the base flocks could be identified and used in the nucleus, they would contribute to the overall genetic gain.

Peart (1979) considered that the initiation and development of sheep group breeding schemes represented a major departure from the established selection, business and sociological patterns long accepted within the sheep industry. The first schemes began in 1967 and expanded quite rapidly. He indicated that this rapid growth was partly generated by the widely publicised results of scientific research and partly by a lack of any visual or measured progress in sheep quality over many years.
Because the first two people to embrace the group breeding scheme concept in 1970 and 1975 were owners of medium sized studs, they were able to convert many of their ram buying clients to the system of group breeding. However the move to this type of breeding system has not been a complete success in all instances and a number of sheep breeders who participated in group breeding schemes decided to return to the stud system.

In South Australia, a former national executive director of the Australian Merino Society, Robert Anderson, withdrew from the scheme and re-established the Glenlossie stud within the traditional stud breeding industry. Other A.M.S. groups at Caltowie, Kingston, Jabuk and on Eyre Peninsula also withdrew from the scheme, electing to continue conducting their Merino breeding programs as nucleus breeding units, but under the auspices of the Merinotech system.

James (1981) reported that if a nucleus is designed primarily to maximise genetic gain while the base population maintains an aim of wool production, the optimum age structures may be different in the two sections of the breeding system. To overcome the potential conflicts caused by this, he recommended the strategies of using cast-for-age nucleus sires in the base or using nucleus sires in the base by AI at the same time they are being used in the base.
England and Litchfield (1990) reported that by 1989, the group breeding scheme, Australian Merino Society, had successfully gathered together 1,000 Merino breeders and reinforced their commitment to performance breeding. However they also report that in 1988, a consultative committee of leading Australian sheep geneticists had recommended that the Australian Merino Society divide its large Australia-wide open nucleus breeding program into a number of smaller regional and environment-specific programs. Following this, a new organisation called the Australian Federation of Performance Breeders was officially constituted in 1990. While this new body was not exclusively comprised of group and nucleus breeding scheme participants, it did represent a number of former Australian Merino Society participants and also had links with the membership of the newer Merinotech group breeding scheme.

Addressing the structural qualities of the Merinotech structure, Carrick and England (1990) reported that open nucleus breeding structures provide the ideal organisational environment in which elements of animal breeding theory can be integrated in a wholly practical and economic way towards well defined objectives. In the particular case of Merinotech, the participating breeding organisations are owned and controlled by breeders at the daughter stud and commercial levels, with the elite flock also being owned by the company of breeders.
According to James (1987b), apart from the genetic advantages offered by cooperative, nucleus and group breeding schemes, one of the most important aspects is that the breeding goals can be defined by the members to meet their own needs. Instead of relying on others to produce the genetic improvement, members of such groups have the future of their flocks in their own hands. He suggests the fact that breeding goals need to be defined by the group members is of great assistance in clarifying objectives which may have previously been quite vague.

A survey of 141 South Australian commercial wool growers by Greenslade (1989) revealed that only 4.9 per cent sourced their rams from group breeding schemes, while 81.9 per cent sourced rams from studs. He reports this survey reflected the continuing reliance by commercial sheep producers on studs for the provision of flock rams and genetic improvement.

While studs breeders still provide the majority of flock rams to the Merino industry, there has been a move by some studs to also participate in the Australian Federation of Performance Breeders system alongside the previously rival systems of nucleus and group breeding schemes.

2.1.3 Ram Use in Commercial Flocks

Gifford and Walkley (1992) reported that commercial sheep flocks produce virtually all the wool and sheep meat in Australia.
In Merino flocks, they see the main objective of the breeding program as being the improvement of profit, primarily by increasing lifetime wool production and quality.

A study by Campbell et al. (1986) surveying a random sample of 327 Victorian sheep producers found that in the Victorian Merino industry, only 15 per cent bred their own rams, and the majority of those who purchased outside rams, did so at the breeder’s property rather than at sales. As a result of a survey in South Australia, Greenslade (1989) found that 10.4 per cent of commercial producers surveyed bred their own ram replacements. This is confirmed by Brien (1988), who observed that most commercial wool growers breed their own ewe replacements, but not their ram replacements. They obtain rams or semen from ram breeders who may be stud breeders or managers of ram-breeding co-operatives. With this breeding structure, he noted that the ram breeders are in a position to largely determine the rate at which sheep in commercial flocks are improving genetically.

Walkley (1987) suggested that improvement of the profitability of commercial wool growing flocks in Australia by genetic means depended almost solely on the breeding objectives pursued and selection practices adopted by stud and co-operative ram breeders. According to Brien & Ponzoni (1992), this simply means that for the great majority of commercial woolgrowers, the choice of where to buy their rams is, to a large extent, going to determine the fibre diameter of the sheep in their flock.
As the breeding direction or "breeding objective" followed by a stud or commercial grower is concerned with the overall merit of the sheep rather than just the fibre diameter, they state that for the traits that a ram breeder is selecting for, the ram buyer's flock will be taken in the same direction.

2.2 Breeders' Selection Policy

2.2.1 Background

Riches and Turner (1955) investigating the possibility of selecting sheep at an earlier age than the industry standard, highlighted that the general practice at that time was eye appraisal in the wool at an age ranging from 18 months to 2 years. The results of their investigation indicated that eye appraisal at any age is considerably less efficient than selection on wool weight for increasing either wool weight or wool value. Turner (1956) believed that extensive fleece measurements on ewes, other than greasy weight, were not warranted on the ground of expense, but in rams a study of the relationship of the fleece components was justifiable, at least in sires used extensively.

Watts (1992) noted that graziers implement their own variations in sheep classing, but central to it all is a careful and thorough inspection of the flock and the individual animals. All ewes and rams need to be classed every year, and preferably twice at three months after being shorn and again close to full wool.
However according to Butler and Horton (1991), as only 40 per cent of ewes in the commercial sector are generally culled, the ewes kept for breeding are little better than the average of the flock as a whole. They highlighted that a small number of well selected rams have a much greater effect on the genetics of these flocks than a greater number of poorer selected rams.

As part of the activities of scientists to promote the use of objective measurement during the 1950's, Butt and Kearins (1987) proposed that the ability of sheep classers to accurately identify top producing sheep without objective measurement was brought into question.

The concept of half classing as promoted by scientists such as Morley (1955a) was misinterpreted by many stud breeders as being a policy for selection based solely on measurement and the resulting years saw very little co-operation between scientists and some stud breeders. This period of history affected the approach to sheep selection adopted by stud breeders. Compounding this, Peart (1990) believed that the original geneticists varied in their ability to promote the results of trials involving objective selection of sheep, while they also certainly did not provide an image of being included as part of the social fabric of the highly structured and very prosperous Merino stud industry.

Ponzoni (1995) further explained the early antagonism between the practice of traditional sheep classing and the use of objective measurements.
He noted that during the 1930's and 1940's when comparisons of sheep classing and fleece weighing were undertaken, the methods normally employed by sheep classifiers did not focus exclusively on fleece weight, but rather an evaluation of the animal as a whole. This approach incorporated assessment of the animals for factors such as conformation, wool quality and faults. He explained that further work conducted in the late 1980's and early 1990's highlighted that sheep classing was more aligned to the use of an index where selection is based on several characters, rather than selection based on a single character such as fleece weight.

Piper and Lax (1992) indicated that typical breeding objectives for Merino sheep generally aim to increase clean fleece weight while either maintaining or improving wool quality. They reported that Merino breeders vary considerably in the emphasis they place on body weight and reproduction rate. In relation to these two characters, some breeders are content to maintain the current performance levels of their flock.

England and Litchfield (1990) reported the wool industry in particular has until recently been slow to adopt proven measurement and breeding practices which could significantly increase the rate of genetic progress towards more profitable commercial sheep enterprises. Their opinion was that all too often, the early adopters, researchers and extension workers have experienced isolation and lack of commercial support in spite of their deep sense of commitment to improving the welfare of the industry. Much effort is being devoted to recognise and overcome of these types of problems.
One such solution was reported by Rogan (1997) who observed that any education or training activities associated with the Rampower performance recording scheme would acknowledge the importance of a balanced approach to measured and non-measured characteristics in sheep selection. While Rampower relies on the formation of a profit-driven breeding objective which sets quantifiable goals and permits the use of objective measurement to influence 60 to 80 per cent of disciplined selection emphasis, the remaining emphasis can be based on subjectively assessed traits of economic importance.

2.2.2 Age of Single Stage Selection and Classing

Gifford and Walkley (1992) reported that in the majority of ram breeding flocks, the ram drop is generally culled sequentially. They indicated that a portion may be culled as early as lamb marking, with the remainder being periodically classed until a major classing when the rams are classified as reserves, flock rams or culls.

Piper (1990) observed that typical recommendations to ram breeders based on 1950-60's research emphasised selection on the basis of objective measurements at 15-16 months of age with 10-12 months fleece growth. This was generally only applied to the selection of reserves which had previously been chosen using traditional visual classing. However in later years with the increase in emphasis on pre-sale objective measurement of wool, demand grew for measurement of fleece weight and fibre diameter for flock rams at the time of sale.
This created a change in stud management to a system where rams were shorn at ages less than 12 months and with around 6 months wool.

Gifford et al. (1995) reported that following the initial change by ram breeders from the traditional practice of visually assessing full-wool sire replacements at hogget age, many studs moved to the practice of visually selecting reserve rams at a younger age. Studs utilising objective data in the selection process generally then only used measurements on the reserve rams at the later hogget age. During the late 1970's, they reported significant change occurred and many ram breeding flocks moved to performance record entire ram drops prior to 12 months of age.

Atkins (1979) reported the supply of production information on flock rams in New South Wales led to the selling of rams in short wool, since the rams had to be first shorn to obtain the measurements. As a consequence, the average age and average length of time between lamb and hogget shearing for flocks contributing samples to the Trangie fleece measurement service were 14.3 and 7.8 months respectively.

According to MacLeod (1991), breeders cannot wait to measure a ram's lifetime production of wool before using him to breed in the flock. Retention of rams for extended periods would increase feeding costs and hence lower profit margins in ram sales.
In addition to the problems associated with having to retain all ram lambs as entires for an extended period of time, she noted that this would also increase the generation interval and slow down genetic progress.

Consequently, the younger the ram is when selected to be part of the breeding stock the better, provided that the selection method is able to accurately identify the best rams.

Atkins and Mortimer (1987) confirm that breeding plans rely on the identification of superior animals at a young age, usually based on single measures of fleece weight and fibre diameter. Walkley (1987) reported that in the majority of ram breeding flocks, the ram drop is generally culled sequentially, with a portion culled as early as lamb marking. The remainder are periodically visually classed until a major classing when the rams are classified as reserves, flock rams or culls. He further observed that almost all ewes in ram breeding flocks are first mated at 18 months of age and subsequently remain in the flock for a further four or five matings unless culled on the basis of reproductive failure.

Atkins and Mortimer (1987) observed that in New South Wales, most rams were measured at 8-12 months of age, with only 6-8 months wool growth. According to Butt and Kearins (1987), the majority of flock rams showed two permanent incisors.
They noted that although for the majority of ram buyers in Australia visual assessment has traditionally been the only available method of selecting rams, there is now an increasing trend to selling rams with performance measurements.

Despite the trend toward early measurement of rams, Metcalfe and Brien (1992) reported a major industry survey indicated that 72 percent of breeders are not confident in using performance records obtained from rams younger than 18 months. The survey also showed that 44 percent of the breeders required a testing age of at least 24 months before they would be confident in the measurement. This is despite ample evidence of the high repeatability of fibre diameter tests conducted at younger ages.

A survey conducted by Agrimark Consultants (1992) confirmed the uncertainty of breeders toward selection and measurement at an early age. The survey found that 89 per cent of the stud Merino breeders believed that sheep were tested too young, while 73 per cent of the commercial Merino producers surveyed held a similar opinion.

Kearins (1991) reported the theory base for objective measurement was derived from experiments that on average used 12 months wool growth at 15 months of age at measurement time.
This was supported by Atkins et al (1990) who reported that historically, recommendations to ram breeders in the Merino wool industry were based on the use of objectively measured fleece weight and fibre diameter at about 15 months of age on a full fleece. This assessment was conducted immediately prior to the selection of sires for first mating at 18 months of age. They suggested that eventually, many studs began to conduct their initial selection of potential sires or reserves using visual selection at younger ages.

Where measurement was included in the selection program, generally only reserve rams were tested at 15 months of age. As a result of the demand for measurement information on fleece weight and fibre diameter for flock rams at the time of sale, they claimed whole drops of rams were commonly measured at ages less than 12 months and often at 9-10 months with 6 months wool growth.

In Queensland, Rose (1990) reported that studs are finding that many clients require rams at 12 months of age so they can acclimatise rams on their property prior to joining. With clients joining earlier than the stud, it is not possible for the studs to easily meet these requirements and also provide accurate measurements.

Occasionally rams that are identified quite early as being superior, are mated at a very young age. Watts (1992) encouraged the test mating of promising young rams as early as 5 to 6 months of age. This may be done by either artificial or natural insemination.
In many studs, Rogan (1982) stated that reserve rams must be identified as young as 6 to 12 months to enable animals to be prepared for shows and sale to other studs, and also to allow culling of unwanted animals and to fit in with flock ram selling requirements.

Rogan also noted that in the case of flock rams, measurements are taken at 10 to 11 months to enable them to be ready for grading and flock ram selling which commences at 12 to 18 months of age. Rose (1986) surveyed Merino studs in Queensland, and found that they all classed rams while they were in the age range of 10 to 18 months.

In a survey conducted for a national symposium on Merino improvement programs in Australia held at Leura N.S.W. in 1987, Walkley (1987) reported that rams were culled at ages ranging from 1 to 16 months, with the average being 6 months. Visual appraisal was used almost exclusively for the animals culled at the earlier ages, while 24% of ram breeders also used visual appraisal exclusively when classing rams as flock or reserve grade at an average age of 14 months. The survey also established that co-operative ram breeding flocks generally culled rams at an early age.
Ponzoni (1979a) reported that a situation frequently encountered in some South Australian studs is the following practice which amounts to taking measurements on animals 11-12 months old with 6-7 months of wool growth, with hogget classing occurring during the period following this:

March - April - Lambs born
July - August - Lambs shorn
Feb. - March, following year - Hoggets shorn and fleece weighed
- other wool measurements taken
- Selection occurs during the following period

A survey of 117 members of the S.A. Stud Merino Sheepbreeders' Association by Ponzoni (1980) revealed that in studs using objective measurement, shearing of ram lambs occurred at an average 4 months of age, classing of rams occurred at an average 11 months of age with an average 7 months' wool growth. Hogget ram shearing occurred at an average 13 months of age with 9 months' average wool growth. Wool growth at classing varied between studs from a minimum of three months to a maximum of 13 months, and from 3 months to 18 months at the hogget shearing.

In a later survey of 115 members of the S.A. Stud Merino Sheepbreeders' Association, Hancock and Cunningham (1987) found that almost all South Australian studs join their ewes and rams at 18 months of age.
Their survey showed that 8 percent of studs mated rams at 12 months or age, and only 11 percent delayed mating of rams beyond 27 months. Atkins (1987) indicated that in New South Wales, rams are first measured at shearing when aged 9-12 months, carrying 6 months' wool growth. It is now commonly accepted practice in the stud industry to initially objectively measure fleece characters when the sheep have a minimum of six months wool growth following an initial lamb shearing.

Rogan et al (1987) reported that evidence for the acceptance of these requirements is given when it is considered that in the seven years to 1985, an average of 88 percent of the Trangie Fleece Measurement Service clients measured rams which were less than 12 months of age with 6-8 months wool growth at the test shearing. They saw this, along with the resultant presentation of rams for sale with only 2-3 months wool growth, as a major departure from traditional management and marketing practices in Merino studs.

According to Rogan (1990), the lamb or weaner shearing is necessary to minimise the effects of spread of birth date, birth type (single/twin) and age of dam (maiden/adult) on the variation in fleece weight and fibre diameter at the later shearing. He also recommended that even at the weaner shearing, the maximum range of lambing date (age) within a measurement group should be no more than 8 weeks. A survey of NSW ram breeders by Casey and Hygate (1992) found that 90 per cent of the breeders conducted the even-up shearing and that this was done at an average age of 4.5 months.
Rogan et al. (1987) also stipulated that the animals must have been managed as one group for the full wool growth period prior to testing.

McGuirk (1987b) reported industry practice is moving towards first measurement at 10-12 months of age. For the purposes of ranking or grading flock rams, there is general acceptance of performance measurement at this age based on as little as six months wool growth. However he states there is uncertainty as to the value of these records as the basis of sire selection.

Kearins and Rogan (1987) indicated that the sampling of sheep with a minimum of six months wool growth following an initial lamb shearing is a compromise between several factors. These are the scientific knowledge that measurement of young animals may suffer from reduced accuracy in estimating genetic potential, and also the management difficulties in subjecting young rams to two shearings between weaning and the commencement of ram selection and marketing at about 12 months of age.

McGuirk (1987b) reported that fine and superfine breeders have made little use of objective measurement in their selection programs, preferring to use subjective assessments of traits such as wool quality and crimp characteristics. Because of this, there is little information on parameters for these sheep.
The information that has been published suggests that fleece weight, even at the stage of hogget shearing, is not particularly predictable. He advised that in light of this fact, breeders should be cautious about following the trend of testing rams at young ages.

2.2.3 Two Stage Selection

An improved selection program now carried out by a number of studs is two stage selection. Ponzoni (1987) reported this is a good approach to the selection of sheep, where all animals are recorded at a first stage of selection based on one or more characters that are simple and cheap to measure, leaving the recording of more expensive characters to a second stage where data is collected on a lesser number of animals. A two stage selection program may either be conducted on the basis of data collected at one shearing when the sheep are aged, for example, 12-16 months, or on the basis of data collected at two consecutive shearings conducted at, for example, age 9-12 months and age 16-18 months.

In a survey of N.S.W. sheep breeders, Casey and Hygate (1992) defined two stage selection as being where two major selection events occur prior to the first joining of the rams. The first selection obtains sale rams and reserve stud sires, while the second obtains sires from these reserves at a later date. Other minor selection events could also occur at lamb marking or weaning prior to the first measurement shearing.
The survey showed that 77 per cent of the ram breeders implemented a two stage selection strategy.

Atkins and Rogan (1986) considered that the second method of two stage selection to be the ideal system for many studs. If rams are first shorn before 12 months of age, Atkins et al. (1990) claim the potential exists to re-shear a selected proportion of these rams with at least 6 months wool growth prior to their final selection as sires. They also see two stage selection as providing the opportunity to intensify the measurement effort at the second stage. The selection procedure also becomes more cost effective when the relatively more expensive or difficult-to-measure additional traits are assessed at a second stage to increase the correlation between the index and the objective.

According to Butt and Kearins (1987), a good number of studs in N.S.W. tested their whole drop of rams at around 9-12 months of age, and then retested an elite group of reserve rams at an older age. They were of the opinion that the two measurements were not combined but used independently, however a combination of the two stages of performance testing would have greatly improved the accuracy.

This trend toward two stage measurement is confirmed by Atkins and Mortimer (1987), who recognised that most studs commonly use a two stage selection process of early identification of reserve rams at 8-12 months of age followed by a second shearing prior to sire selection at 18 months of age.
This is backed up by an extensive survey of 161 New South Wales Merino stud breeders, conducted by Casey (1990) who concluded that 68 per-cent of studs actually do their first measured assessment of wool traits prior to the animal turning 12 months of age. The survey also showed that some form of two-stage assessment is currently used by 77 per-cent of breeders, with more than half of these sheep having more than six months' wool growth at the second shearing in order to make effective use of the second record. Relatively small age effects on parameters for fleece weight has been shown by Atkins (1987) to increase selection accuracy for a two-stage strategy compared with single stage selection. His work particularly highlighted the improvement in accuracy over selection based on first shearing information only.

Atkins et al (1990) claimed an efficiently operated two-stage selection strategy would lead to substantial benefits of more than 25 per-cent, over single stage selection based on measurements at 10 months of age. The benefits become marginal, with the benefit reducing to 10 per-cent, when compared with single stage selection at 16 months of age. However despite the popularity of two stage selection, Rogan (1982) reported that a survey of 145 clients of the Trangie Fleece Measurement service conducted by Sheep and Wool Advisers of the New South Wales Department of Agriculture in 1981, showed that 60% of studs did not class before measurements were taken.
2.2.4 Parental Selection

An interesting method of selection was analysed by Hopkins and James (1977), when they compared the relative merits of parental selection amongst adults, with the more usual progeny selection conducted only amongst hoggets. On the majority of properties, once an animal is selected for inclusion in the breeding flock, it remains there until it dies or is culled for age. Parental selection amongst adults is based on a continual analysis of the estimated breeding value of all parents of the following year's crop of offspring, irrespective of age. In this way, overlapping generations can be compared, and individuals of each generation are progressively culled if there exists progeny of superior breeding value to replace them. The work of these two researchers determined that the use of the parent selection strategies consistently resulted in superior genetic responses when compared with the more traditional selection of progeny only.

A simple method of implementing this progressive culling program amongst adults according to James (1981) would be to use a series of coloured ear tags to denote the relative superiority of each individual, and the year each should be culled. Despite this, the actual in-flock complexity of the parental selection method would be a large barrier to its adoption by many stud Merino breeders.
2.3 Objective Measurements & Selection Indices

2.3.1 Background

According to Butt and Kearins (1987), the need for the wool industry to utilise objective measures of performance in order to maximise genetic improvement has been recognised by scientists and extension officers since the early 1950’s. However Brien (1990b) reports that the performance recording schemes initially developed for Merino sheep on a regional basis in Australia during the 1950’s did not receive wide support. Casey (1987) confirmed this and reported that apart from a small band of innovative ram breeders, measurements were little used in the marketing of rams in the two decades after fleece measurement became commercially available. Winter (1987) confirmed this, and indicated that despite increased grazier awareness of genetic theory and the principles of recommended sheep breeding programs, there had been limited adoption of these programs in practice within the sheep breeding industry. However, as predicted by Peart (1979), the presence of co-operative nucleus breeding schemes within the Merino industry has acted as a large stimulus for the traditional stud industry to adopt more objective selection methods.

James and Roberts (1979) reported that objective measurement is important because it replaces the sheep classer’s subjective art or mystique, which cannot easily be taught to other people who may desire to gain the skill of evaluating breeding stock. The application of measurement can be learnt quickly and cheaply.
As objective measurements can also be defined accurately, their use does not involve the expense of employing an outside sheep classer each time selection and culling is carried out in the flock.

The lack of obvious improvement in fleece weights during the period from the 1920's until the 1940's has been identified by Morley (1980) as the key factor in stimulating the research work in this area. In the early days of objective measurement, Peart (1979) claimed that as scientific recommendations conflicted with traditional selection procedures and the accepted notion of quality, sheepmen sought advice from the classifiers, who dismissed the scientists' claims. During the 1970's in South Australia, the rural media often carried extremely emotive articles on the subject issued by both sides of the argument.

The information base available encounters difficulties when attempting to measure actual genetic improvement. According to McGuirk (1987b), over the period between 1946/47 and 1984/85, average wool cuts in the national flock increased by 0.02 kg/head/year or slightly less than 0.5 per cent per year, while actual lamb marking rates increased by 0.21 percentage points/year which represents an annual rate of improvement of 0.3 per cent per year of the average figure of 72 per cent lambs marked per ewe joined. He claims it is obvious that the sheep breeding research program has not coincided with a major improvement in performance.
Peart (1990) recognised that in the minds of many stud breeders, a great objection to measurement is that it immediately makes half of the rams below average. This creates an immediate selling problem for the breeders. He also highlights that many breeders initially over-enthusiastically selected for fleece weight alone, resulting in an increase in micron and lowering of market price.

Ponzoni (1995) reported that early in the 1970’s following more than twenty years of effort by extension and research workers to promote acceptance of objective measurement, only 15 percent of studs in New South Wales were using measurement. However in 1976 following the establishment of a simplified low cost performance recording scheme by the NSW Department of Agriculture, acceptance of measurement in that state escalated. By 1985, approximately 50 percent of studs in New South Wales were submitting samples to the scheme for objective measurement.

A setback to the adoption of objective measurement in Western Australia has been identified by Brien et al. (1991). They reported that controversy developed in 1989 between stud Merino breeders and the W.A. Department of Agriculture over suggestions that a 'Code of Practice' and an accreditation scheme be implemented for ram breeders. The subsequent antagonism that developed between the two bodies hindered the adoption of objective selection techniques, including the Woolplan scheme.
A survey of South Australian commercial Merino producers by Greenslade (1989) found that although nearly all respondents used visual assessment to some degree in their ram selection, 81 per cent also utilised objective measurements. Of those using objective measurements, there was a large concentration of producers who chose rams for themselves. The survey also showed that 72 per cent of studs were providing objective measurements for their clients.

This trend agrees with the results of a survey conducted by Agrimark Consultants (1992), where 97 per cent of the stud Merino breeders surveyed recognised that objective measurement provides valuable support for visual assessment, while 92 per cent of commercial Merino producers considered this was the case. A further survey of 329 Australian stud Merino breeders conducted by Butler et al. (1995) identified that 36 per cent of the breeders used performance measurement information to a great extent and a further 59 per cent made some use of it. Only 5 per cent claimed they did not utilise objective measurement information.

In assessing the state of the stud Merino industry in 1996, Brash and Rogan (1997) reported that although change did occur, recognition of performance breeders increased far slower than many had expected. However they indicated that the general profile of objective measurement did improve and overall, stud Merino breeders had become more familiar with handling numbers.
Morgan (1987) reported that in the early days of fleece measurement, if a breeder wished to select for more than one parameter, he was forced to use procedures which involved independent culling levels, as the procedures and computer resources required for the more efficient and logistical simpler selection techniques were not generally available. The observations of Turner and Young (1969) agree with this notion and they say the calculations involved in the selection index could become tedious when the number of traits under selection exceeded three. However they observed that greater accessibility to high speed computers in recent times overcame these difficulties.

Morgan (1987) also suggested that as these deficiencies were overcome, there was a proliferation of selection indices, not all of which were based on sound assumptions. An advocate for the use of selection indices was Atkins (1987), who observed that as practical breeding plans were usually based on a number of selection criteria, a selection index that utilised the selection criteria was always the method that would maximise genetic response. However in relation to the use of a selection index, Turner and Young (1969) highlighted that although the gain in economic terms was greater, as compared with independent culling levels or tandem selection, the genetic advance in individual traits was smaller when the index was used compared with selection based on a single character.
Lax and Jackson (1987) reported that selection schemes for the Merino industry require multi-trait selection methods, and the most feasible method is by the use of a selection index which uses parameter values and economic weights to obtain a single index equation to maximise genetic progress. These two researchers felt there were three areas within the wool industry where selection indices could be of considerable use. The first area involved selection of rams in the studs, subsequent use of the rams in other locations and the prediction of genetic response from their selection in terms of ewe and wether wool production. Their second area of application was for the selection of two or more traits using information from an individual alone or combined with that from relatives. As an example, this could include selection for fibre diameter, clean fleece weight and body weight. The third major application they saw within the wool industry was the ability to hold one or more traits fixed or with restricted change, while changing other traits. For example, a common goal in the wool industry is to increase clean fleece weight whilst holding fibre diameter unchanged. In the absence of an index, Goddard and Jones (1987) suggested there was a tendency for people to use independent culling levels which placed equal emphasis on all traits. However, similar to Morgan (1987), they believed selection indices often suffered from errors, particularly concerning economic weights and genetic parameters which were hidden from the user. The economic aspects of the selection index concept in the Woolplan system were also highlighted by Brien (1990c), who reported that the Woolplan index score was actually an estimate of the overall economic value of an animal as a potential parent.
2.3.2 WOOLPLAN

According to Fleet et al. (1988), Woolplan was a performance recording service that utilised production records of an individual sheep to assess its genetic merit as a parent. As background to the formation of Woolplan, Ponzoni (1995) highlighted that although the performance recording schemes developed in the various states of Australia were quite similar, they were not identical. This lack of consistency was identified as a problem for any stud breeders and woolgrowers who attempted to use information from flocks in the different states.

Ponzoni (1987) reported that in 1983 a Working Party on Sheep Performance Testing and Recording Services (SPTRS) presented a comprehensive report to the Animal Production Committee. In 1984, the Standing Committee on Agriculture established a Sheep Performance Recording Co-ordinating Committee to develop detailed guidelines for the various types of performance recording identified by the SPTRS report.

As a result of the sub-committee's work, Woolplan was developed. Woolplan was an Australian scheme designed to meet the performance recording needs of ram breeding flocks in the Merino and other non-pedigreed wool sheep breeds.
Morgan (1987) indicated that because it incorporated the skills of geneticists and breeders, Woolplan was perhaps the most important development in sheep performance recording since the establishment of fleece measurement services in the 1950's. Ponzoni (1987) reported that Woolplan differed in many ways from other schemes developed earlier in Australia, because it was available on a national basis, whereas earlier schemes were developed locally in various states often around particular fleece testing services with virtually no between-State transfer of schemes. By offering a more comprehensive approach to breeding objectives and selection criteria, Butt and Kearins (1987) saw Woolplan as offering the potential for greater genetic gains and overall profitability.

Maxwell and Brien (1988) stressed that Woolplan did not aim to replace traditional visual assessment of sheep, but rather provided an aid to sheep selection. Lewer and Brien (1988) reinforced this and reported that Woolplan should not be used in isolation but in conjunction with any visual aspects that are important to economic return and client demand.

According to Rose (1990), it was important to see that breeders appreciated that Woolplan was a recording scheme and was as such an efficient tool to incorporate into well designed breeding programs. She recognised that while the extension and implementation of Woolplan did have a number of practical problems, it did have a number of features which were very beneficial in getting studbreeders to look objectively at the technical and the practical aspects of their breeding programs.
Ponzoni and Brien (1993) reported that Woolplan enabled the breeder to consider five traits in the breeding objective. These were clean fleece weight, average fibre diameter, reproductive rate, hogget live weight and weight of cast-for-age ewes. They stipulated that Woolplan presented breeders with four standard index options that incorporated each of these five traits, plus a fifth option in which a breeder could decide which traits were included in the breeding objective and the economic value of each trait.

Because of a recognition that the industry contained ram breeding flocks with a variety of breeding objectives, Ponzoni (1988) reported that in the development of Woolplan different options were made available in Woolplan. Rogan (1990) outlined the four standard breeding objective options which breeders could choose from:

Option #1  All Woolplan traits free to change genetically (CFW, hogget weight, cfa weight, lambing rate all increase; fibre diameter decrease).

Option #2  CFW, hogget weight, cfa weight, lambing rate all increase; fibre diameter doesn't change.

Option #3  CFW, hogget weight, cfa weight all increase; fibre diameter decrease; lambing rate doesn't change.

Option #4  CFW, hogget weight, cfa weight all increase; lambing rate and fibre diameter don't change.
Brien and Ponzoni (1990) reported that the four Woolplan options were also available to producers using greasy fleece weight in place of the clean fleece weight. If the information was available, they reported Woolplan adjusted records of fleece and body weights for differences caused by sheep being:

- born to a maiden rather than a mature ewe;
- born and/or raised as a twin, rather than as a single;
- born late in the lambing period rather than early;
- grazed in different randomly allocated management groups.

Gifford et al. (1992a) reported that options #1 and #2 corresponded to micron premiums of 5 and 1 to 2 per cent respectively. As many breeders felt there was justification in placing more emphasis on the reduction of fibre diameter, options #3 and #4 were modified to correspond to micron premiums of 10 and 20 per cent respectively.

Atkins et al (1990) recognised Woolplan as being an integral part of the two stage selection process. This involved the provision of a first-stage Woolplan report following the first test shearing. The first-stage report assumed the actual recorded measurements were unbiased estimates of the whole drop mean and variance for fleece weight and fibre diameter. As the sheep included in the second-stage shearing have been selected, at least partly, on the results of the first-stage measurements, the mean and variance of the measured traits relative to the whole drop, was altered.
Accordingly, the records of each animal recorded at the second stage were adjusted so that they were directly comparable to records that would have been available if all animals had been retained. A second-stage Woolplan report would then be produced to permit a final selection of the sheep.

According to Rogan (1990), Woolplan provided a means of comparing the merit of individual rams with other rams of the same age and management background. The emphasis was placed on the relative merit of rams for a range of measurable characteristics rather than the absolute fibre diameter, yield, fleece weight etc. of individual rams. He felt that absolute figures could be misleading due to the impact of non-genetic factors such as feeding, age and season on such characteristics.

Ponzoni et al. (1992) explained that while it is generally accepted that Merino breeders will carry out some selection based on a subjective appraisal of wool attributes such as dry wool or poor colour, the only wool traits included in the breeding objective of Woolplan are clean fleece weight and mean fibre diameter.

As most of the selection pressure concerning wool traits will therefore be on these two traits, they feel breeders have the right to question the genetic consequences of such a simplification.
Piper and Lax (1992) noted that it was a common misconception that breeders using Woolplan were precluded from considering non-measured conformation and wool quality traits simply because they were not included in the formal Woolplan breeding objectives. They dismissed this idea, highlighting that breeders could define their breeding objective to include any trait they considered to be important. Woolplan was simply a tool to inform breeders how best to use the objective measurements for each animal to maximise genetic progress in economic merit.

Considerable emphasis was put on the effort to extend the concept of Woolplan to all sectors of the Merino sheep breeding industry. Brien (1990a) reported that common to most Australian states was a division of the Woolplan extension campaign into two sections. One aimed at ram breeders who formed the main audience for direct Woolplan service usage and the other aimed at the majority of woolgrowers, who normally purchased their ram replacements.

A number of people expressed concern that Woolplan could have negative long term effects on fibre diameter variability, however Ponzoni & Brien (1993) reported these concerns were unjustified. He reported that in fact, Woolplan options no. 1, 3 and 4 were likely to have favourable consequences.
In response to a belief by some breeders that the measurements upon which Woolplan was based had low repeatabilities, Brien et al. (1991) recommended the conduct of a series of regional studies on repeatabilities of performance recording data and Woolplan indexes. They felt the regional repeatability trials could be completed over a short period of time and for a modest cost.

A survey by Agrimark Consultants (1992) highlighted the polarised attitude of stud breeders towards Woolplan. It was shown that 42 per cent agreed that Woolplan was an accurate way of ranking rams, while a further 46 per cent of stud breeders felt that it was not. In fact, many of the stud breeders also felt that Woolplan did not have any more to offer them than other objective measurements.

Rose (1990) observed that because Woolplan was marketed as a standardised national scheme, it did meet with some scepticism from breeders who did not see such a scheme as suitable for such a diverse array of breeders' requirements Australia-wide. In Queensland however, she felt the few options that were offered, did accommodate the needs of most Queensland stud breeders. However in relation to the national industry, the stud Merino industry in Queensland is a small component.

According to Ponzoni (1995), while Woolplan was able to evaluate individuals within a flock, it did not enable the comparison of individuals in different flocks.
He reported that in June 1993, a meeting of industry representatives, extension, research and wool laboratory personnel decided to create a new National Genetic Evaluation Co-ordinating Committee to support the adoption of measurement, genetic evaluation and breeding technologies in the Australian sheep industry. The broad role of this committee supported within-flock sire evaluation schemes such as the Woolplan service, as well as sire evaluation schemes.

According to Brien (1993), several main issues hampered the adoption of Woolplan. In particular, he identified the lack of industry ownership in the development of the scheme and the lack of confidence of many breeders about its practicality. Despite these perceived shortcomings, he did identify Woolplan as having a number of significant achievements. In particular, these were the management and co-ordination of quality control at fleece testing laboratories, the promotion of best practice in data processing, the provision of a focus for research and development and also its role as a vehicle for technology transfer.

McGuirk (1987b) suggested that the methodology used to establish breeding objectives in Woolplan was somewhat limited and required a major research thrust. Woolplan included only those characters that influenced returns as part of the objective, using marginal economic values based on returns per unit increase in the character but adjusting for any increased costs in feed or labour needed to achieve that gain.
He believed a more flexible approach would have been to develop a profit function or equation in which both returns and costs would have been included as part of the objective.

It is the opinion of Ponzoni (1995) that although between strain and bloodline comparisons could lead to significant improvement within flocks and the industry in general, the real key to long term genetic progress was selection of individuals within ram breeding flocks. To do this, he indicated breeders had access to schemes such as Woolplan.

The progress and implementation of the Woolplan scheme was formally examined on a regular basis and Brien (1994) reported that in August 1993, the Wool Research and Development Corporation accepted the recommendations of a review to replace Woolplan with a genetic improvement system of much broader scope. The replacement for Woolplan was also to incorporate sire evaluation schemes.

Rogan (1995) reported that the International Wool Secretariat took over the responsibility for the replacement to Woolplan and in February 1994 funded a technology transfer project called RAMPOWER: Wool Breeding Services. This project was directed by a National Co-ordinating Committee, with majority representation by wool producers and Merino ram breeders from all Australian mainland states.
Brash and Rogan (1997) reported that following a number of years' work, the Rampower project replacement to Woolplan was launched in early 1997. The name of the Rampower project software package which was designed to provide animal evaluation ranging from simple analysis of objective performance measurements to extremely complex BLUP analysis of Merino data was Rampower '96.

This software provided a major extension and re-focusing of the previously available services. They indicated that while Rampower '96 was a successor to Woolplan, there were many differences which aimed to overcome the perceived failings of Woolplan and also provide the best outcomes for wool testing laboratories and sheep breeders. One of the biggest advantages was the flexibility for breeders to access assistance in defining their breeding objective and then to have a corresponding index developed for their particular needs.

It was reported by Rogan (1997) that the Rampower 96 performance recording software could produce reports which included actual values and/or phenotypic deviations and/or estimated progeny values and/or index values which incorporate information on one or all of a wide range of characteristics. These characteristics were:

- clean fleece weight
- greasy fleece weight
- yield
- average fibre diameter
- co-efficient of variation of fibre diameter
- staple strength
- faecal worm egg count
- body weight
- birth type (twin/single)
- birth date
- dam age
- pedigree

Rogan (1997) also indicates that other characters such as scores or comments on pigmentation, wool style, conformation, skin type, fleece rot/fly strike, wool colour and staple strength could be recorded and reported by the Rampower 96 software. As Rampower could accommodate both measured and non-measured characteristics, Merino breeders could identify the optimum balance of all information in order to achieve the desired levels of genetic improvement.

2.4 Genetic Background of Repeatability:

Van Vleck et al. (1987) reported that repeatability is a ratio of variance components and represents the degree of association between measurements on the same animal for traits which are measured at different ages. They acknowledged that an assumption made in the definition of repeatability is that the genotype for the trait is the same each time the trait is measured.
The ratio depends on the variances of two types of environmental influences: permanent environmental (PE) and temporary environmental (TE) influences. They defined permanent environmental effects as those which influence all observations made on the individual, while a temporary environmental effect influences only a single observation on the individual.

As the reference of Van Vleck et al (1987) omits genetic variance, Atkins (pers. com.) suggested the following definition of repeatability:

\[ t = \frac{G + PE}{G + PE + TE} \]

Mortimer (1987) further defined repeatability as the extent to which animals selected for superiority early in life retain that superiority throughout their life. She sees the most useful application of repeatability estimates, in the prediction of increases in lifetime production of the current flock, obtained through the early culling of animals. Depending on the repeatability estimate, selection may either be based on one record at a set age, or on the analysis of the mean of a number of records taken at different ages.

Turner and Young (1969) reported that variation between repeated measurements on the same animals at different times may be due to systematic or random changes in the environment, or to errors of measurement; repeatability measures the fraction of the variation from one animal to another which is due to permanent differences, as distinct from these variable changes.
They indicated that with a high repeatability, the fraction of variation due to non-permanent effects is small, so that any decrease in it will not have a very marked influence on the total variation. However as the repeatability falls, the fraction of variance due to non-permanent effects increases, and any procedure which can decrease it becomes of greater importance.

They also suggested that if repeatability is high, animals rank consistently high (or low) in a flock to the extent that elimination of low producers will raise the lifetime average production of the selected animals by an appreciable amount. Also, high repeatability means that selection for lifetime production can be based on a single record. However when repeatability is low, the accuracy of the selection can be improved by basing selection on the mean of two or more records.

MacLeod (1991) reported that repeatability can be expressed on a percentage scale, from 0 to 100 percent. The closer the value is to 100 percent, the more precise the early measurement is as a predictor of the same trait at a later age. According to Lewer (1993b), as repeatability is not a genetic characteristic, it offers little useful information about selecting individuals as parents. However it is very relevant to the performance of the current generation.
2.4.1 Repeatability and between-age Single Character Phenotypic Correlations:

2.4.1.1 Wool and Body Characters:

A study conducted by Riches and Turner (1955) investigated the possibility of selecting sheep at an earlier age than the industry standard and was primarily designed to assess the reliability of appraisal at 6-8 months of age. They assessed the whole of one ewe drop, initially amounting to 1,000 individuals run as one flock under ordinary semi-arid station conditions at Cunnamulla, Queensland. The sheep were classed at 6 and 8 months of age, and again on two occasions one week apart at approximately 19 months of age.

The researchers found there was little difference between appraisals at 6 and 8 months, however at either age approximately 30 per cent of the animals were given a different rating from the one given later at 19 months. This compared with 19 per cent for which classing was inconsistent at the two 19 month appraisals.

The anomalies that exist between performances at early selection ages and later ages of selection were a matter of concern for Gifford et al. (1990). They reported that within the South Australian Merino industry, it was essential that breeding programs implemented in studs to genetically improve commercial flocks are based on accurate parameters obtained at ages which reflect stud industry practice. They indicated that specifically, correlations are required between ram performance at 10 months and 16 months with 6 months wool growth and lifetime performance.
The observation that early measurements are not well correlated with later measurements is not shared by all researchers. Wade et al. (1992) estimated repeatabilities using 224 fine-wool Merino rams shorn at 13 months of age carrying 7 months wool and then shorn at 22 months of age (ie. 9 months later) carrying 12 months wool growth. In addition to repeatability calculations for a range of fleece characters, the researchers also calculated repeatability estimates for the four clean fleece weight Woolplan Index options. The researchers found that the level of the repeatability estimates indicated that the 13 month measurements were a reliable indication of performance at 22 months.

However Walkley (1987) reported that most genetic and phenotypic parameter estimates available for wool characteristics in Australian Merinos were obtained on sheep aged 15-18 months with 12 months' wool growth.

This observation is in agreement with Gifford et al. (1992b) who also reported that despite this, selection decisions are often made on an assessment of the sheep at a younger age and with the aim of predicting the breeding value for performance at later (adult) ages. In support of this, Atkins (1987) reported that while Merino rams in New South Wales are commonly first shorn at 9-12 months of age carrying six months' wool growth, no real estimates of repeatability have been published from animals at such young ages.
There is ample evidence from researchers and geneticists that although the current practice of ram breeders is to base their selection decisions on animals aged ten months with six months wool growth, there remains a dearth of repeatability estimates for animals in this category. Further research is required to substantiate the early age selection recommendations currently being promoted amongst the ram breeding sector.

The reliability of early age measurements has been disputed in many areas, however phenotypic correlation values of measurements taken at various ages related to later-life performances do provide a good indication. In New South Wales, the Trangie Fleece Measurement service stipulated that rams being assessed for fibre diameter, yield, fleece weight and body weight must be 10 months of age and have at least six months' wool growth following the lamb shearing. Kearins and Rogan (1987) explained the basis for this guideline is that the repeatability of rankings based on measurements of animals younger than this, and with less wool growth, are likely to be significantly lower than those based on the more traditional hogget shearing records of 15-18 months of age with 12 months' wool growth. This is largely because of the confounding effects of maternal influence and relatively wide variation in animal age due to the date of birth within the lambing period.

However despite the level of phenotypic correlation between ages, Rose (1985) reports it is almost as efficient to select for sheep production on the earliest adult records as on the mean of two records.
She indicates the slight loss in efficiency is compensated by a higher gain per year because of early selection and the early disposal of surplus sheep.

To date, the various researchers involved in establishing repeatability estimates and phenotypic correlations have utilised groups of sheep containing either ewes or rams. The compatibility of estimates obtained from trials utilising both sexes of animals was demonstrated by Young et al. (1960). These researchers conducted a trial at the CSIRO “Gilruth Plains” National Field Station using 159 unselected medium-wool Peppin Merino ewes and 148 unselected rams. The researchers found that the differences in repeatability estimates for the ewes and rams were very small and non-significant. They concluded that estimates of repeatability obtained from ewes can be regarded as applicable to rams.

The work of many researchers has been analysed in detail by Mortimer (1987), who also came to the conclusion that repeatability estimates obtained for greasy and clean fleece weights did not vary significantly between strains of Merino or between sexes. These results and those of other researchers confirm that both ewes and rams can be used in trials designed to obtain standard repeatability estimates. However while the claim that repeatability estimates do not vary significantly between bloodlines may in fact be true, there has generally been insufficient work involving some of the Merino bloodlines to justify this. In particular, information is lacking in respect to repeatabilities involving the South Australian strong wool Merino strain and more work is required to correct this situation.
Appendix: 1. contains the individual reference summary tables of wool and body character repeatability estimates and phenotypic correlations.

2.4.1.1.a. Estimated Repeatability of Greasy Fleece Weight:

The trial conducted by Young et al. (1960) using 159 unselected medium-wool Peppin Merino ewes and 148 unselected rams established a range of repeatability estimates between 0.64 and 0.66. These estimates were very similar to those obtained in a trial involving 1,095 Queensland bred medium Peppin Merino ewes run at the Toorak Field Station in Queensland by Beattie (1961) to estimate the repeatability of seven fleece characters and three body characters. His repeatability estimate for greasy fleece weight was 0.68.

Support for these repeatability estimates also comes from the work undertaken by Wade et al. (1992). They calculated a repeatability estimate of 0.66. The same repeatability estimate was obtained by Atkins et al. (1992) who analysed variation in production traits between Merino bloodlines in NSW wether trial comparisons.
conducted from 1981 until 1991. The trials involved 895 individual teams, representing 133 different Merino bloodlines. Using this mass of data, average repeatability of greasy fleece weight was calculated as 0.66.

Work by Heaton-Harris et al. (1969) produced an even higher estimated repeatability of 0.78. These researchers conducted a trial at the University of New South Wales field station at Hay, to assess the differences in the repeatability of characters in Merino rams receiving two different feeding regimes. The rams represented seven separate Peppin and non-Peppin medium wool Merino studs and the repeatability estimates were calculated by simple correlation on characters displayed by both groups between ages 18 months and 30 months. A similarly high repeatability estimate of 0.79 was obtained by Mullaney et al. (1970) who conducted a series of observations on mixed age ewes in four Merino (2,160 records) flocks in the Western Districts of Victoria.

A repeatability estimate of 0.61 for greasy fleece weight was obtained in a trial involving four South Australian Merino flocks described by Ponzoni (1979a). In this trial, the pooled repeatability estimate was between a value obtained with first measurement taken at 4-6 months of age and a value obtained with first measurement taken at 14-16 months of age.
By contrast to the work already cited, Ford (1961) obtained far lower repeatability estimates of greasy fleece weight in Australian Merino ewes and rams. His work utilised records taken at ages from 6 months to 6 years and produced an estimated repeatability of 0.4 to 0.5. Turner (1977) conducted an analysis of the work previously carried out by Morley (1955b), Mullaney et al. (1970), Young et al. (1960), Kennedy (1967) and Young et al. (1963). Her summary of the repeatability estimates for measurements collected on fine and medium wool Peppin bloodline Merino sheep established a range of 0.60 to 0.80 for greasy fleece weight.

Apart from the work of Ford (1961), all of the report values for estimated repeatability of greasy fleece weight tend to be in general agreement. A summary of the various reported estimates is contained in Table: 2.4.1.1.

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>REPEATABILITY</th>
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<tbody>
<tr>
<td>Young et al. (1960)</td>
<td>0.64 - 0.66</td>
</tr>
<tr>
<td>Beattie (1961)</td>
<td>0.68</td>
</tr>
<tr>
<td>Ford (1961)</td>
<td>0.40 - 0.50</td>
</tr>
<tr>
<td>Heaton-Harris et al. (1969)</td>
<td>0.78</td>
</tr>
<tr>
<td>Mullaney et al. (1970)</td>
<td>0.79</td>
</tr>
<tr>
<td>Turner (1977)</td>
<td>0.60 - 0.80</td>
</tr>
<tr>
<td>Ponzoni (1979a)</td>
<td>0.61</td>
</tr>
<tr>
<td>Wade et al. (1992)</td>
<td>0.66</td>
</tr>
<tr>
<td>Atkins et al. (1992)</td>
<td>0.66</td>
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</table>
Although the repeatability estimate for greasy fleece weight over the lifetime of a sheep does provide an extremely valuable tool for breeders, it is the phenotypic correlation between measurements taken at a set age and the actual performance of the animal at later ages that may be of greater significance in many instances. Reviewing a number of previous trials conducted by other researchers, Ponzoni (1979a) reported that most repeatability estimates for greasy fleece weights seemed to fall roughly into two groupings. The first grouping was phenotypic correlation between measurements taken at 4-6 months of age, and again at 15-16 months of age, resulting in estimates of 0.4 to 0.6 which have usually been considered as low. The second grouping was phenotypic correlation between measurements taken as two-tooths at 14-16 months of age, and again as four tooths approximately 12 months later. Phenotypic estimates for this grouping range from 0.6 to 0.8, and have been considered to be high.

Reporting data analysed from four South Australian Merino flocks in a joint project with an extension officer and private producers, Ponzoni (1979a) indicated that as a predictor of future performance, greasy fleece weight measurement at 12 months of age with 6 months of wool growth is somewhat inferior to measurement at 14-16 months of age with 12 months of wool growth. This conflicts with unpublished experimental evidence from Trangie, showing that the repeatability of rankings on greasy fleece weight on ten month old rams with six months' wool were not significantly lower than previous published estimates based on older sheep with 12 months' wool growth.
Young et al. (1960) had previously investigated the phenotypic correlation between records at a single age and the total of "lifetime" performances in medium-wool Peppin Merino ewes. Their phenotypic correlation at the 15/16 month measurement was 0.72, which agrees with the range reported by Ponzoni (1979a). At each of the 30, 42 and 54 month measurements, the correlation was reported to be 0.86. The researchers also calculated phenotypic correlation between records taken for the ewes at 15-16 months and later ages, in addition to an investigation into the phenotypic correlation between pairs of records taken at consecutive ages for medium-wool Peppin Merino rams. The researchers concluded that sex differences for all characters were small and non-significant.

In a trial involving a flock of medium wool Peppin Merinos analysed for various characters at a weaning age of 5.5-6.5 months and also at a hogget age of 15-16 months, Young et al. (1965) reported that as the phenotypic correlation between the two ages was 0.43, greasy fleece weight at weaning is only moderately repeatable. They concluded that the low repeatability of fleece weight at weaning makes selection on this trait relatively inefficient.

Rogan et al. (1995) conducted a repeatability trial using 277 medium wool Merino ram lambs at Trangie. Part of the trial assessed the effect of weaner shearing on the correlations between subsequent unadjusted fleece measurements taken at 10 and 16 months of age. The results showed that in relation to greasy fleece weight, the repeatability estimates were significantly affected by the effect of weaner shearing.
They concluded that where selection at 10 months of age places emphasis on greasy fleece weight, there is a substantial loss of accuracy if the animals had not been previously shorn as lambs. For sheep that had previously been shorn as weaners, they reported a correlation of 0.52.

In an extensive examination of the phenotypic parameters for South Australian Merino sheep conducted at the Turretfield Research Centre, Ponzoni et al. (1995a) reported a similar correlation of 0.55 for sheep in the same age range as those studied by Rogan et al. (1995). Ponzoni et al (1995a) utilised a base resource flock of 2,000 South Australian Merino strain ewes representing the Collinsville and Bungaree family groups, mated to 162 sires of these families, with the subsequent performance testing of 2,200 young rams born over a four year period. Phenotypic correlations were calculated for various objectively measured characters at 10 and 16 months of age, with 6 months wool at the time of shearing.

Brash et al. (1997) also investigated the phenotypic correlation of greasy fleece weight between the two ages of 10 and 16 months, and calculated a value of 0.54. These researchers utilised rams of the fine, medium-Peppin and broad wool Merino strains, all the progeny of 969 ewes and 68 rams.

As outlined in Table: 2.4.1.2., there appears to be general agreement between the various reports in relation to the phenotypic correlation for greasy fleece weight between various ages of measurement and later performance.
It is quite apparent that the value of the phenotypic correlation increases as the age of initial measurement on the animals becomes greater.

Table: 2.4.1.2.
PHENOTYPIC CORRELATION OF GREASY FLEECE WEIGHT
AGE OF MEASUREMENT Vs LATER AGE

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>5-8 months Vs later age</th>
<th>9-12 months Vs later age</th>
<th>13-18 months Vs later age</th>
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</thead>
<tbody>
<tr>
<td>Young et al. (1960)</td>
<td></td>
<td></td>
<td>0.72</td>
</tr>
<tr>
<td>Young et al. (1965)</td>
<td>0.43</td>
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<td></td>
</tr>
<tr>
<td>Ponzoni (1979a)</td>
<td>0.40 - 0.60</td>
<td>0.60 - 0.80</td>
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<tr>
<td>Rogan et al. (1995)</td>
<td></td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td>Ponzoni et al. (1995a)</td>
<td>0.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brash et al. (1997)</td>
<td></td>
<td>0.54</td>
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</table>

In a trial involving fifteen Merino bloodlines, each comprising 100 randomly selected ewes, Atkins & Mortimer (1987) estimated parameters for each annual fleece expression between 1 and 6 years of age. At each shearing, the weight of the total fleece was recorded. It was concluded that phenotypic correlations involving hogget fleece weights were consistently lower than correlations among adult weights and that indirect selection on hogget weight would be about 65-70 percent efficient. This efficiency is based on hogget weights recorded on 15 month old animals, with 12 months wool growth.

Based on an analysis of the results of Atkins and Mortimer (1987), Atkins (1987) reported that there is at least a need to consider hogget and adult fleece weights as two separate traits.
In contrast to this, a study of the economic aspects of developing breeding objectives for Merino sheep by Jones (1982) assumed a correlation between adult fleece characteristics and hogget characters of slightly less than one.

2.4.1.1.b. Estimated Repeatability of Clean Fleece Weight:

The work by Young et al. (1960) involving unselected medium-wool Peppin Merino ewes and rams established repeatability estimates for clean fleece weight of 0.59 - 0.68. Also using medium-wool Peppin Merino ewes, Beattie (1961) obtained a repeatability estimate of 0.65, which was in the mid-range of the Young et al. (1960) estimates. The analysis by Atkins et al. (1992) of data from NSW wether trials involving a wide range of Merino bloodlines conducted between 1981 and 1991 produced a repeatability estimate of 0.62, which is in general agreement with Young et al. (1960) and Beattie (1961).

Other researchers have however reported repeatability estimates that are somewhat higher. The estimate reported by Heaton-Harris (1969) was 0.71. This estimate was obtained using animals representing seven separate Peppin and non-Peppin medium-wool Merino studs. Wade et al. (1992) calculated a repeatability estimate of 0.75, using fine-wool Merino rams. Also using fine wool Merino sheep, Mullaney et al. (1970) calculated an even higher repeatability estimate of 0.78 in Western Victorian flocks.
In work to establish a profit equation for the definition of the breeding objective of Australian Merino sheep, Ponzoni (1986) estimated the average repeatability in relation to clean fleece weight (C.F.W.) to be 0.80. In this work, he separated the traits expressed in two classifications of non-breeding animals. These were lambs up to 6 months of age and hoggets from 6-18 months, and also the traits expressed in breeding ewes aged 1.5-5.5 years. A review of repeatability estimates by Turner (1977) reported a range of 0.60 - 0.80.

All reports of repeatability estimates for clean fleece weight conclude that the character is medium to highly repeatable. A summary of the various reports is contained in Table: 2.4.1.3.

<table>
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The values for phenotypic correlation of clean fleece weight between age of measurement and later age appear to be spread quite widely. For animals aged 9 - 12 months, Atkins (1987) reported the relatively high phenotypic correlation range of 0.70 - 0.90.
By contrast, Ponzoni et al. (1995a) reported a phenotypic correlation of 0.55, while Brash et al. (1997) reported a value of 0.54. Based on an analysis of data from medium and strong wool Merino sheep, Hynd et al. (1997) reported a range of phenotypic correlation values between 0.40 and 0.55.

The spread of estimates is also apparent for animals measured between 13 and 18 months of age. Hynd et al. (1997) reported a phenotypic correlation for clean fleece weight of 0.60, while Young et al. (1960) reported a value of 0.72. Despite this, there is a clear trend that the value for phenotypic correlation of clean fleece weight becomes greater as the age of measurement increases.

Mortimer (1987) reported that in relation to clean fleece weight, the high repeatability values indicated that animals which had a high ranking in comparison to their contemporaries at an early age tended to retain that superiority at later ages. A summary of the reported phenotypic correlation values is contained in Table: 2.4.1.4.

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>9-12 months Vs later age</th>
<th>13-18 months Vs later age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young et al. (1960)</td>
<td></td>
<td>0.72</td>
</tr>
<tr>
<td>Atkins (1987)</td>
<td>0.70 - 0.90</td>
<td></td>
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<tr>
<td>Ponzoni et al. (1995a)</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>Brash et al. (1997)</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>Hynd et al. (1997)</td>
<td>0.40 - 0.55</td>
<td>0.60</td>
</tr>
</tbody>
</table>
2.4.1.1.c. Estimated Repeatability of Mean Fibre Diameter:

Based on a wide range of reports, the repeatability estimates for mean fibre diameter range from 0.50 to 0.83. Using medium-wool Peppin sheep, Young et al. (1960) reported estimated repeatability values of 0.50 - 0.54. Although Beattie (1961) provided early support for this estimate when he reported an estimated repeatability of 0.53 for medium-wool Peppin sheep, further studies by other researchers indicated that these estimates were somewhat low.

Working with fine-wool Merino sheep, Wade et al. (1992) established an estimated repeatability of 0.67, while Mullaney et al. (1970), also utilising fine-wool Merino sheep, reported an estimated repeatability of 0.68. After analysing data from a large number of NSW wether trials involving a wide range of Merino bloodlines, Atkins et al. (1992) reported a repeatability estimate of 0.76.

However the upper level of the estimated repeatability range for mean fibre diameter was increased somewhat when Heaton-Harris et al. (1969) reported a value of 0.83, using Peppin and non-Peppin medium-wool Merino sheep for their trial. Turner (1977) reported the range of repeatability estimates as 0.50 - 0.80.

Despite the diverse nature of the repeatability estimates for mean fibre diameter outlined in Table: 2.4.1.5., none of the references listed specifically indicate the performance of the strong-wool South Australian Merino bloodline. There is a need to further extend the list of repeatability estimates to encompass this bloodline.
Table: 2.4.1.5.
REPEATABILITY ESTIMATES FOR MEAN FIBRE DIAMETER

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>REPEATABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young et al. (1960)</td>
<td>0.50 - 0.54</td>
</tr>
<tr>
<td>Beattie (1961)</td>
<td>0.53</td>
</tr>
<tr>
<td>Heaton-Harris et al. (1969)</td>
<td>0.83</td>
</tr>
<tr>
<td>Mullaney et al. (1970)</td>
<td>0.68</td>
</tr>
<tr>
<td>Turner (1977)</td>
<td>0.50 - 0.80</td>
</tr>
<tr>
<td>Wade et al. (1992)</td>
<td>0.67</td>
</tr>
<tr>
<td>Atkins et al. (1992)</td>
<td>0.76</td>
</tr>
</tbody>
</table>

Even when measured at an early stage, the phenotypic correlation of mean fibre diameter between age of measurement and later age appears to be quite high.

When measured at 9-15 months of age, Rogan et al. (1995) reported that medium-wool Merino sheep at Trangie had a phenotypic correlation of 0.69. This is only slightly below the phenotypic correlation of 0.72, reported by Ponzoni et al. (1995a) when assessing South Australian Merino flocks. After assessing fine, medium-Peppin and broad-wool Merino strains, Brash et al. (1997) reported an even greater phenotypic correlation value of 0.77.

Phenotypic correlation values for animals aged 9 - 12 months recently reported by Hynd et al. (1997) were 0.60 - 0.70. However the phenotypic correlation reported by these researchers for sheep aged 13 - 18 months was in the higher end of the range, being 0.80. Young et al. (1960) also reported a high phenotypic correlation of 0.77 for sheep measured at age 13 - 18 months.
Atkins (1987) reported that while there is at least a need to consider hogget and adult fleece weights as two separate traits, no such differentiation on fibre diameter is necessary. Atkins et al (1990) also reported that selection at a young age has little apparent influence on the efficiency of selection for fibre diameter, despite industry fears to the contrary. Referring to survey results by Casey (1990), Atkins et al (1990) reported that one-third of New South Wales Merino studs (that use a two stage selection program) restrict their measurement at the second shearing to fibre diameter only, the trait that makes a much lesser contribution to increased selection efficiency compared with fleece weight.

Confirming the high correlation between mean fibre diameter measures taken at early ages and later performance, Mortimer (1987) reported that repeatability is relatively high for performances measured after weaning. In the comparison trial between sheep that underwent a weaner shearing prior to the measurement shearing and sheep that were measured without a prior lamb shearing, Rogan et al. (1995) concluded that the repeatability estimates for mean fibre diameter in the two treatment groups were very similar. Where selection was influenced by measurements of fibre diameter at 10 months of age, they reported that lamb shearing had little or no effect on the accuracy of selection.

Table: 2.4.1.6. provides a summary of the phenotypic correlations of mean fibre diameter for two ages of measurement in relation to later age performance.
Table: 2.4.1.6.
PHENOTYPIC CORRELATION OF MEAN FIBRE DIAMETER
AGE OF MEASUREMENT Vs LATER AGE

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>9-12 months Vs later age</th>
<th>13-18 months Vs later age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young et al. (1960)</td>
<td></td>
<td>0.77</td>
</tr>
<tr>
<td>Rogan et al. (1995)</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>Ponzoni et al. (1995a)</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>Brash et al. (1997)</td>
<td>0.77</td>
<td></td>
</tr>
<tr>
<td>Hynd et al. (1997)</td>
<td>0.60-0.70</td>
<td>0.80</td>
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</tbody>
</table>

2.4.1.1.d. Estimated Repeatability of Body Weight:

Young (1959) reviewed the available estimates for repeatability of body weight measurements taken on Merino sheep and reported a range between 0.50 and 0.80. Although this range is considered to be very wide, results of later research indicate that the most common estimated repeatability value tends to be in the upper end. Working with medium-wool Peppin sheep, Beattie (1961) reported an estimated repeatability of 0.80, while Heaton-Harris et al. (1969) derived a value of 0.84 from their investigations with Peppin and non-Peppin medium-wool Merinos.

Also working with medium-wool Peppin Merino sheep, Young et al. (1960) established a range of 0.67 - 0.73. Ford (1961) studied Merino ewes and rams aged from 6 months to 6 years and reported an estimated repeatability range of 0.60 - 0.70. Using fine-wool Merino sheep for their investigation, Wade et al. (1992) reported an estimated repeatability of 0.73.
While most studies to date have represented a limited range of bloodlines, several reports indicate estimated repeatability values that have been derived from analysis of studies involving a number of Merino types.

When Turner (1977) examined the values obtained by other researchers, she concluded that the most appropriate estimated repeatability was 0.70. An analysis of NSW wether trial data involving 133 separate bloodlines by Atkins et al. (1992) reported an estimated repeatability of 0.67.

A summary of the studies into repeatability estimates for body weight in Merino sheep is contained in Table: 2.4.1.7.

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>REPEATABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young (1959)</td>
<td>0.50 - 0.80</td>
</tr>
<tr>
<td>Young et al. (1960)</td>
<td>0.67 - 0.73</td>
</tr>
<tr>
<td>Beattie (1961)</td>
<td>0.80</td>
</tr>
<tr>
<td>Ford (1961)</td>
<td>0.60 - 0.70</td>
</tr>
<tr>
<td>Heaton-Harris et al. (1969)</td>
<td>0.84</td>
</tr>
<tr>
<td>Turner (1977)</td>
<td>0.70</td>
</tr>
<tr>
<td>Wade et al. (1992)</td>
<td>0.73</td>
</tr>
<tr>
<td>Atkins et al. (1992)</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Using a flock of medium wool Peppin Merinos analysed for greasy fleece weight and body weight at a weaning age of 5.5-6.5 months and also at a hogget age of 15-16 months, Young et al. (1965) reported that body weight weight at weaning had a phenotypic correlation of 0.35, indicating it was only moderately repeatable.
From this estimate, they concluded that body weight measurements at weaning may only be of some value if Merino sheep were being produced for slaughter at an early age.

In contrast to the moderate phenotypic correlation obtained when measurements are made at an early age, the phenotypic correlation of body weight increased quite considerably when measurements are made at 9 - 12 months of age. Using medium-wool Merino rams, Rogan et al. (1995) reported a phenotypic correlation of 0.87 between measurements taken at this age and performance of the same animals at a later age. High phenotypic correlation was also obtained by Ponzoni et al. (1995a) who reported a value of 0.78 in South Australian Merino sheep. Brash et al. (1997) also obtained a high phenotypic correlation of 0.72 in fine-wool, medium-wool Peppin and broad-wool Merino strains.

At even older measurement ages, the high phenotypic correlation values are maintained, as illustrated by the value of 0.81 reported by Young et al. (1960). The trial by Rogan et al. (1995) examined the effects of lamb shearing on repeatability estimates and concluded that where selection was influenced by measurements of body weight at 10 months of age, lamb shearing had little or no effect on the accuracy of selection. A listing of the phenotypic correlation values for body weight at various ages of measurement is included in Table: 2.4.1.8.
Table: 2.4.1.8.
PHENOTYPIC CORRELATION OF BODY WEIGHT
AGE OF MEASUREMENT Vs LATER AGE

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>5-8 months Vs later age</th>
<th>9-12 months Vs later age</th>
<th>13-18 months Vs later age</th>
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</thead>
<tbody>
<tr>
<td>Young et al. (1960)</td>
<td></td>
<td></td>
<td>0.81</td>
</tr>
<tr>
<td>Young et al. (1965)</td>
<td>0.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rogan et al. (1995)</td>
<td></td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td>Ponzoni et al. (1995a)</td>
<td></td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>Brash et al. (1997)</td>
<td></td>
<td></td>
<td>0.72</td>
</tr>
</tbody>
</table>

2.4.1.1.e. Estimated Repeatability of Woolplan Indices Rankings:

There have been very few investigations into the estimated repeatability of selection indices rankings, particularly Woolplan indices. However Wade et al. (1992) calculated estimated repeatabilities for the four clean fleece weight Woolplan indices. The researchers reported that the level of repeatability estimates, ranging from 0.73 to 0.74, indicated that the 13 month measurements were a reliable indication of performance at 22 months of age. They also observed that despite the unfavourable correlation between fibre diameter and clean fleece weight, the Woolplan indices had similar repeatabilities to the individual traits.

2.4.1.1.f. Estimated Repeatability of Other Wool and Body Characters:

Over the past fifty years, considerable research effort has been expended to establish repeatability estimates for other wool and body characters in Merino sheep. Such characters are wrinkle score, face cover, staple strength, crimps per inch and yield. As these characters are not crucial to this research project, they are not dealt with in detail.
However summary tables of estimates established for these characters by Young et al. (1960), Beattie (1961), Heaton-Harris et al. (1969), Mullaney et al. (1970), Turner (1977), Wade et al. (1992) and Atkins et al. (1992) are contained in Appendix: 2.

2.4.2 Repeatability - Follicle Curvature and Skin Characteristics

Hynd (1992) reported that the use of skin characteristics has been suggested as an alternative or additional early selection criteria for sheep. He stated that this direction is due in part to a recognition that most of the genetically-determined follicular patterns (numbers, sizes, shapes) are largely in place soon after birth. While most follicles are initiated by birth, many may not produce a fibre until the lamb reaches 6 months of age.

According to Gifford et al. (1995), the emphasis on skin characteristics by sheep classers and ram breeders is based on the fact that it is the skin that nourishes and supports the population of fibre-producing follicles. While emphasis may be placed on skin characteristics, it is the blood supply containing amino acids to the skin that promotes wool growth. These researchers observed that skin quality is routinely assessed in many ram breeding flocks and is a subjective character useful for undertaking a preliminary culling of rams. However Hynd (1992), indicated that at best, skin selection will only be useful as an aid in early selection decisions.
Nay and Jackson (1973) reported that because it is relatively unaffected by nutrition, the skin character of follicle curvature may be measured at the weaning stage with reasonable confidence. These two researchers estimated the correlation between follicle curvature at weaning and a number of wool characteristics at 15-16 months of age at 0.2 to 0.4. They indicated this relationship could provide an avenue to accurately conduct preliminary culling of ram lambs at weaning, provided a final culling based on clean fleece weight and fibre diameter is also conducted when the animals reach 15-16 months of age. They concluded that although follicle curvature is not a character currently able to be easily assessed on-property, it holds the potential to become an important aspect of sheep classing in the future.

Hynd et al. (1997) reported that selection of Merino sheep on indirect traits such as skin characters will only be effective if they are more accurate indicators of lifetime wool production when measured on young animals. Although considerable research has been conducted into skin traits and their relationship to economically important characters, the researchers indicated that to date none have been shown to satisfy this criteria.

2.4.3 **Repeatability - Fertility Characters**

According to Rose (1985), repeatability of fertility, either number of lambs born or number of lambs weaned, is low. This means that culling ewes on their maiden ewe performance will produce little lifetime gain.
However she reports that the step from single to multiple births is more repeatable than that from barrenness to single birth which indicates selection for twins is likely to raise lifetime lamb production in the current flock more rapidly than selection against barrenness.

Fogarty (1984) reports that in the past, selection recommendations have generally involved selection for fecundity or twinning rather than complex traits or other component traits. This is because of the small size of predicted responses to selection for fertility through the culling of barren ewes, the ability to select ewes and rams at an early age and recommendations that environmental rather than genetic modifications be used to increase lamb survival. However he does note that there is increasing evidence of genetic variation in all components of sheep fertility and that selection for reproductive components other than fecundity should also be emphasised. Another view by Beilharz and Luxford (1984) puts forward the concept that even the relatively small increases resulting from selection for litter size or ovulation rate in sheep will need appropriate improvements in the environment if they are not to have deleterious side effects.

Repeatability estimates for fertility characters were calculated by Young et al. (1963) at "Gilruth Plains" using four experimental mating groups in a strain of 700 medium Peppin Merinos (Table: 6.3.1. in appendix 3.). The researchers concluded that these estimates of repeatability indicate that lifetime gains in fertility by selection of ewes are likely to be small.
In analysing data from the CSIRO field stations at Cunnamulla and Deniliquin, Turner (1966) concluded that the culling of dry ewes would not lead to any appreciable lowering of the incidence of dry ewes in the current flocks being investigated. She also concluded that culling on lamb-rearing would not be worthwhile as a means of raising survival rate in the current flock. These conclusions are an indication of the low repeatability of these two fertility traits and the lack of benefit to be gained from utilising them in a selection program.

A review conducted by Turner (1977) outlined repeatability estimates for several fertility characters in Merino ewes (Table: 6.3.2. in appendix 3.). Purvis et al. (1987) reviewed published estimates of repeatability of fertility (ewes pregnant, or lambing, of ewes joined) in various breeds of ewes. For Australian Merino ewes, they listed repeatability estimates of ewe fertility as being in the range 0.05 to 0.17 and repeatability estimate for reproduction rate (number of lambs weaned per ewe joined) in the range 0.04 to 0.14 (Table: 6.3.3. in appendix 3.). A world-wide review of repeatability estimates obtained for “lambs born/ewe lambing: litter size” was conducted by Land et al. (1983). They found that for two Australian Merino flocks, the average repeatability was 0.17 (Table: 6.3.4. in appendix 3.).

In unpublished data cited by Kelly (1984), J.P. Hanrahan estimated repeatability of embryo survival in Merino ewes as an average figure of 0.11, but with a range of 0.07 to 0.15.
Working with flocks of ewes, including Merino, Haughey et al. (1985) established repeatability estimates ranging from 0.05 to 0.17 with an average of 0.10 for the ratio of lambs weaned to lambs born. A review by Atkins (1987) estimated the repeatability of NLW (number of lambs weaned) as 0.15, and NLB (number of lambs born) as 0.15.

Because of the low repeatability and heritability estimates associated with reproduction and fertility traits in sheep, Purvis et al. (1987) indicated that it may be inefficient to include many of these traits in a selection program. However in contrast to this view, a trial conducted by Lee and Atkins (1996) using 15 random-bred Merino bloodlines showed that the relationship of the combined weaning performance at the first and second annual reproductive cycles with reproductive performance in later life suggested that gains were possible in the current flock from culling with emphasis on low fertility and rearing ability. In their trial, ewes that were dry at 2 and 3 years of age subsequently reared only half as many lambs as ewes that had reared lambs at 2 and 3 years of age.

2.4.4 Repeatability - Animal Health Factors

Intimately associated with production characters are various animal health conditions, and brief mention must be made to these. Raadsma and Rogan (1987) reviewed the incidence of fleece rot and body strike susceptibility of sheep, and the effect of implementing a culling policy based on these factors. Overall, they concluded that susceptibility is highly age-dependent.
For example, they cite Belschner (1937), who reported that both fleece rot and body
strike are both more severe in animals aged less than 12 months than older
animals.

This is backed up by data and observations from numerous formal and informal
investigations. Raadsma and Rogan (1987) conclude that repeatability estimates
may well depend on the age at which repeat observations are made.

Repeatability estimates for fleece rot resistance ranging from 0.06 to 0.21 have
been reported by Atkins and McGuirk (1979) for ewes aged one year and also two-
to-six-years. The wide range in estimates is due primarily to the actual incidence in
fleece rot during each of the years the observations were made. This has direct
implications for an on-farm sheep breeding enterprise, where the ability to utilise
repeatability estimates of both fleece rot and blowfly strike as a direct aid for culling
is greatly limited by the dramatic year-to-year variations in environmental conditions
affecting the sheep.

2.4.5 Phenotypic Correlations between Measured Characters

Over a four year period, Ponzoni et al. (1995b) examined phenotypic correlations on
2,200 young South Australian Merino rams representing the Bungaree and
Collinsville family groups. Objective measurements were taken at ages 10 and 16
months, with 6 months wool at shearing (Table: 6.4.1. in appendix 4.).
For example, the phenotypic correlation between greasy fleece weight and clean fleece weight at 10 months was 0.88, while the phenotypic correlation between clean fleece weight and fibre diameter at 16 months was 0.35.

Skerritt et al. (1997) utilised a group of 3,314 medium Peppin Merino and fine wool Merino sheep to calculate parameters for wool follicle traits. In this study, phenotypic correlations were estimated for a number of characters, including four commonly measured fleece characters (Table: 6.4.2. in appendix 4.).

In a trial using 5,100 animals in the CSIRO fine wool Merino flock to assess whether follicle density can be used to enhance genetic improvement in Merino flocks, Purvis and Swan (1997) calculated phenotypic correlations for a number of fleece and body characteristics (Table: 6.4.3. in appendix 4.). Brash et al. (1997) calculated phenotypic correlations for a set of six traits by two ages relevant to industry two-stage selection methods for young Merino rams. Measurements were taken at 10 months of age and 16 months of age (Table: 6.4.4. in appendix 4.).

In a study of selection for skin traits as a means of increasing the rate of genetic progress in Merino breeding programs, Hynd et al. (1997) compiled a table of phenotypic parameters based on a combination of estimates obtained in the South Australian Merino Turretfield Resource Flock and also accepted values currently used in Central Test Sire Evaluation for medium and strong wool Merinos (Table: 6.4.5. in appendix 4.).
2.5. Genetic & Environmental Interactions:

Woolaston (1987) indicated that in the presence of genotype x environmental interactions, genetic differences cannot be accurately described without reference to the environment to which they apply. He warned that changes in rankings of breeds, strains or sires could clearly lead to errors when the results of a genetic comparison in one environment were extrapolated to another. If only one trait was being considered, he indicated environmental effects would result in the actual differences being either greater or less than predicted, however the differences would all be in the same direction within one environment. He indicated the main problem would occur when a composite trait such as a selection index was examined, because an interaction affecting one or more of the component traits could lead to an erroneous choice of genotype.

The problem of variations in performance of traits, and indeed relative rankings, between environments, was described by Falconer (1981) as being due to the fact that different sets of genes influence traits in different environments. Work on wool growth characters conducted by Black and Reis (1979) showed that as the ranking of individuals is not affected by the level of nutrition, the plane of nutrition, or environment, should not affect genetic progress. Despite this, Black (1987) reported that as the response in wool growth to nutrition is greater in animals of higher genetic potential, the difference between individuals will be easier to observe at higher planes of nutrition. He does stress however, that the animals will maintain their ranking under any plane of nutrition.
While recognising this fact, Williams (1987) shares the concerns of others that genetically superior sheep are far more sensitive to environmental fluctuations, and genetic comparisons conducted under less than ideal nutritional conditions will greatly reduce the ease of comparison between animals. In a trial designed to examine differences in the repeatability estimates obtained from two groups of one hundred and fifty 2.5 year old Merino wethers of a similar background, run in two separate climatic zones at Broken Hill and Julia Creek, Eady et al. (1987) reported that the environmental differences did not significantly affect the estimates obtained at either location. Repeatabilities for clean fleece weight, fibre diameter, and liveweight were estimated by intra-class correlation with each location, based on initial data collected at shearing when the wethers were aged 2.5 years, and data subsequently collected at shearings 12 months and 22 months later. The estimate of repeatability of clean fleece weight, using the three fleece weights, was 0.53 for the Julia Creek location, and 0.43 for the Broken Hill location. Liveweight repeatability was 0.76 at Julia Creek, and 0.72 at Broken Hill, while repeatability for fibre diameter measurements was 0.60 at Julia Creek, and 0.54 at Broken Hill.

2.6. Non-Genetic Environmental & Maternal Effects:

Heaton-Harris et al. (1969) conducted a trial at the Hay Field Station to assess the repeatability of characters in Merino rams run under paddock conditions and also stud conditions involving shedding and supplementary feeding.
It was found that there was no significant difference in the repeatability figures obtained from the two groups of sheep, and the researchers concluded that there is no reason to think that repeatability is affected by feeding treatment.

Kearins and Rogan (1987) indicated that the stipulation of the Trangie Fleece Measurement service that rams being tested must have at least six months' wool growth following the lamb shearing is in recognition of the fact that in very young animals, age, maternal and birth type effects are likely to reduce the accuracy in estimating genetic potential. This guideline is justified by work conducted by Young et al. (1965), where in a flock of medium wool Peppin Merinos analysed for greasy fleece weight and body weight at a weaning age of 5.5-6.5 months and also at a hogget age of 15-16 months, maternal handicaps were quite evident at the earlier weaner shearing age. Atkins et al. (1990) reported that maternal and early environment effects account for 10 per-cent of the total variance of 10 month fleece weight. They indicated that in the past, selection was often conducted at this age using visual techniques, with measurement being employed on a smaller group at 15-16 months of age. As initial selection based on measured performance at this young age is increasingly being used in addition to the visual selection, they propose there is some offset between reduced selection efficiency at young ages and greater accuracy of selection using measurement.
James and Roberts (1979) reported that despite the potential effect of maternal factors, there is no need to despair if records are incomplete and corrections cannot be made. This thought is shared by Gregory (1982), who concluded from investigations into genetic selection responses amongst S.A. Merino sheep, that there would be no likelihood of any great improvement in response from any hogget selection scheme by correcting any of the main production traits for variations due to type of birth and age of dam.

Mortimer (1987) concluded that because environmental sources of variation are of such significance, in instances where they cannot be taken into account great inaccuracies in breeding value estimation may occur. She specified such examples as age at measurement, birth-rearing type, and age of dam. However in relation to fibre diameter and yield, repeatability is relatively high for performances measured after weaning, and little improvement in the accuracy of estimates is obtained by adjusting records for known environmental effects.

Rogan et al. (1995) reported that in most cases, Merino ram breeders are not able to correct for such non-genetic sources of variability because birth type (twin or single), dam identity or age and date of birth are not routinely recorded. However their study did look at the effect on subsequent measurements, of initially shearing sheep at weaning.
The weaner shearing reduced the effects of early-life environmental variability to the extent that the relationship between fleece weight rankings at 10 and 16 months was twice as high, when compared to records taken on sheep that were not shorn as weaners. Weaner shearing did not have a significant impact on the repeatability of fibre diameter, yield or body weight measurements.

The inability of breeders to record possible non-genetic early life maternal effects is highlighted by a survey of fleece testing laboratory use by Brien (1994). Of the 455 breeders who received Woolplan reports in the 1991/92 financial year, only 17 (3.7 per cent) supplied information on the type of birth, 6 (0.01 per cent) supplied information on the date of birth, 18 (4.0 per cent) supplied information on the age of dam.

Turner (1961) reported that if sheep born as twins or out of young dams were not identified at selection they would suffer a heavier culling rate if selection was based on fleece weight, however the effect on genetic progress and current production would be negligible. This was partly because the twins actually provided a greater number of animals available for selection than if the births had been single. This meant the higher selection differential arising from the smaller proportion saved, more than offset any deficiency from the maternal handicap.

Lewer (1993a) identified that birth rearing effects were the main maternal influence on hogget wool traits.
Despite the large effects of maternal influence, he did not identify dam age as a significant source of variation. The age effect of dam was also found to be insignificant in a trial conducted by Brown et al. (1968). They found that the wool production of progeny of 2 year old dams did not differ significantly from the progeny of adult ewes.

Turner and Young (1969) reported that in Australia and in other countries where sheep are run in extensive paddocks with a minimum of supervision, a lamb’s dam and litter size are frequently not known, so that no adjustments for maternal handicap can be made. Where no adjustments are able to be made, they report three effects on gains. These are that the rejection of the progeny of 2-year old ewes will tend to increase the generation interval and decrease genetic merit, that genetically superior animals may be culled and that rejection of animals from multiple births will in effect be selection against multiple births.

According to Kearins (1991), a ram breeder could reduce the inaccuracies that the birth effect can cause to repeatability if:

- The lambing period is restricted to six weeks;
- The day or week of lambing can be supplied and adjusted for;
- The birth type can be determined and adjusted for;
- Even up shearing at or following weaning;
- The age of assessment is as old as practical at first stage (the selection of reserve sires and sale rams);
A two stage selection procedure incorporating repeat measuring is adopted for the selection of sires from reserves.

In a project involving a resource flock of 2,000 South Australian Merino ewes and rams acquired from four major South Australian studs, Gifford et al. (1993) were able to examine the effects of environmental factors on ram production characters. With rams measured at 10 months of age, the age of dam only had a significant effect on greasy fleece weight, clean fleece weight and coefficient of variation of fibre diameter. The type of birth/rearing effects were only of significance for greasy and clean fleece weights, liveweight and scrotal circumference. When the rams were measured at 16 months of age, age of dam only had a significant effect on greasy and clean fleece weights, yield and liveweight. Type of birth/rearing effects were only significant for greasy and clean fleece weights, liveweight and scrotal circumference.

In addition to these characters, other characters investigated in this trial included mean fibre diameter, standard deviation of fibre diameter, staple length, staple strength, cover, lock, skin quality, wool colour, wool handle and wool condition.
2.7 Barriers to Adoption of Selection Indices and Objective Measurement:

As has been demonstrated by the reluctance of the Australian wool sheep breeding industry to wholeheartedly embrace breeding programs recommended by industry organisations in the past, it would be naive to expect producers to unreservedly accept the advice of research and extension agencies. There must be an examination of the barriers to the adoption of such advice. Rogan (1982) indicated that the major limitation to improvement associated with the adoption of selection indices in the Merino industry is the education of Merino breeders and service personnel in the implementation of existing recommended breeding programs such as Woolplan and Rampower. All rams within the stud flock must have been managed identically for the period of wool growth prior to testing in order to estimate the genetic merit of rams in a stud flock and accurately rank them relative to a group average.

However according to Kearins and Rogan (1987), this requirement has been difficult to achieve on some large ram breeding enterprises where, because of large numbers of young rams, breeders have been compelled to draft rams into smaller groups at, or soon after weaning, and differentially manage these groups. They indicated that from a measurement point of view, this has precluded the ranking of rams relative to the whole drop average, and in some cases, caused confusion about the apparent genetic merit of some rams.
As many rams are sold at 12 to 14 months of age, doubts concerning repeatability of ranking of fleece weight at 12 months, presentation of rams with little wool growth, and a requirement that fleece weighing is carried out with no more than 6 to 8 months wool are reasons for limited acceptance of recommended breeding programs (Anon. 1977).

Peart (1990) recognised that despite objective measurement being in use since 1950, there is very little commercial proof that objectively measured lines of sheep or studs are head and shoulders above the rest of the stud industry. He attributed this lack of substantiation to the fact that the industry wether trials are largely won by the finest micron sheep. Sheep being 2.5 microns finer than average tend to win any wether trial, irrespective of the amount of their light fleece weights. He feels this has generally blinded the public to the fact that progress can be made by selection in both wool weight and micron at the same time.

Regarding the conflict between objective measurers and traditionalists which has raged since the 1950's, Rogan (1982) reported that in the 1980's the problem had decreased. He puts this down to a possible decline in emphasis among stud sheep classifiers on maintenance of particular stud types and increased attention to production traits. Rogan also indicated the decreased level of conflict had resulted from a softening of attitudes among promoters of objective measurement, in their attempts to use it as an aid to selection rather than a replacement of visual standards.
Butt et al. (1990) indicated that while animal breeding research had been financed by industry and government, application of results often lacked support. On going technical servicing should be a high priority and requires long term commitment by extension organisations. They state that in order to have credibility, extension officers must be able to effectively relate to breeders and understand the situation under which they operate.

It has been argued by Savage and McGuirk (1976) that some of the Merino studs’ well-defined selection procedures tend to hinder the use of objective measurements as a selection aid. For example, the sale of flock rams in full wool prevents any check on the reserve rams’ superiority on greasy fleece weight and also prevents any ranking of flock rams on other than a visual assessment of merit. They consider that it will often be necessary for studs to alter their shearing times if objective measurement is to be used in the screening and ranking of rams. In the South Australian stud Merino industry during the late 1990’s, there has been an increasing trend toward the sale of Merino rams in short wool. In theory, this will assist in the use of more applicable objective measurements at the time of sale.

McGuirk and Rose (1979) noted another reason for the relatively poor uptake of objective measurement use as being a recognition by the industry that experienced stud classers employing subjective sheep classing regimes are actually quite efficient in identifying heavy wool cutters.
One of the major factors to contribute to the more general adoption of fleece measurement as a selection aid, according to McGuirk (1987a) was the widespread introduction of pre-sale testing of wool in the early 1970's. This increased producer interest in, and understanding of, fleece measurements. He also attributed the adoption of wool testing data by sheep breeders to the change by a number of studs from the traditional practice of disposing of flock rams in full wool, to their sale in short wool with measurement information.

It is considered by many authors that one of the barriers to the full implementation of objective selection methods amongst the stud industry is the cost involved. After investigating the optimal allocation of test funds in selection for genetic gain, Wade and James (1990) concluded that a major problem that must be overcome is the maximisation of genetic gain within the restrictions of a budget. Because more selection pressure is able to be applied to rams than to ewes in Merino wool producing enterprises, more funds are often made available to ram testing. However they found the greatest genetic gain will result from additional testing of all ewes using a cheap testing method such as greasy fleece weight.

James and Roberts (1979) agreed that consideration must be given to the fact that the breeder has a total measurement budget and that there is some optimum manner in which the budget needs to be allocated between measurement and the animals.
The overall size of the measurement budget needs to be justified and it must be recognised that to a breeder measurements are simply a means to an end. As this end is genetic improvement within the breeder's flock, measurements must therefore pay for themselves by producing a greater value in genetic gain than their costs.

Atkins and Barlow (1990) identified that a real barrier to adoption is the number of generalist advisers that attempt to extend complex technology, when their own understanding is incomplete. However they feel that computer extension aids will do much to help overcome this problem, but there still remains a need for specialist advisers.

It is the conclusion of Hamersley (1987) that the stud Merino industry and geneticists have yet to identify and share general agreement on the joint research objectives. He indicated this may be partly due to the fact that key researchers seem to have difficulty in acknowledging that the stud industry continues to be successful because of its highly competitive and heavy commercial orientation. Stud breeders do respond to innovation, however unless they can see obvious advantage in a new idea in terms of its potential to increase demand for the end product. Hamersley suggested it is unlikely that there will be any overwhelming response from stud breeders. This thought is shared by Curtin (1992) who acknowledged that farmers will respond to innovation if they see any obvious monetary advantage.
In a survey of 329 stud Merino breeders located throughout Australia, Butler et al. (1995) identified that there was a genuine lack of understanding of the principles of applying measurements. It was concluded that a number of barriers to objective measurement and performance recording needed to be overcome. These included suspicion about the accuracy of the fleece tests and also the ram age at which testing could be conducted with confidence.

2.8 Improving the Application of Objective Measurement Information:

Ponzoni et al. (1992) suggested that the speculative nature of breeding programs should always be taken into consideration. They stated that current selection decisions should be made with the aim of resulting in more profitable animals at some time in the future. Therefore they considered attention must not only be given to present market conditions, but more importantly it should also look to market conditions that are likely to be in force in the foreseeable future.

According to Atkins et al. (1990), selecting Merinos for measured wool traits at 9-10 months of age involved a cost in accuracy of selection compared with selection at 15 months. However they noted this reduction in accuracy can be completely offset through the use of the early measurements as a screening selection that can be supplemented with later records before final selections are made.
For modern sheep breeding technology to be adopted successfully, Butt et al. (1990) recognised that there needs to be a compromise between maximum selection efficiency and industry acceptability. As subjective traits are important to ram breeders, there is a need for breeders, researchers and extension services to work co-operatively. Extension programs must provide high priority to top tier breeding programs and also offer breeders workable and efficient means of evaluating breeding options.

Atkins et al. (1990) recognised the inaccuracies encountered with early visual assessment of Merino sheep and the need to design management systems to allow a second visual assessment at a later stage prior to final selection. They reported that as the basic structure of visual assessment and objective measurement systems is similar, it would be relatively cheap and simple for breeders who utilise visual classing, to include measurements at each selection stage with the need for little structural change.

Hucker and Sharrock (1992) questioned the fact that until now very few commercial sheep growers have applied any objective measurements, apart from greasy fleece weight, to their breeding ewes. They indicated that as ewes contribute half the genetic influence to progeny, a more precise breeding program involving traits such as fibre diameter in the ewe may accelerate progress.
Hamersley (1987) suggested that instead of questioning why a stud breeder does not make greater use of objective measurements, researchers and geneticists should adopt an approach of discovering why the stud breeder is successful.

Peart (1990) stated that the only way that performance recording will be more widely adopted in the industry is through the emergence of commercial evidence that the most profitable Merinos are those that have been performance selected and that more money can be made from them than Merinos selected via traditional methods of visual appraisal.

Ponzoni (1995) reported that the slow pace at which adoption of objective measurements have been adopted by the industry has been more due to the nature of the technology rather than to a real conflict of aims between the defenders of traditional breeding and the advocates of performance recording. He stated recent joint work between sheep classers and geneticists had shown there is ample scope for a co-operative approach between traditional breeding and performance recording. This approach is reinforced by Rogan (1997) who reported that the Rampower performance recording scheme permitted the combined use of objectively measured traits and also subjectively assessed traits of economic importance.
3. MATERIALS & METHODS:

3.1 MATERIALS

3.11 Property

3.1.1.a General Description:

The field trial was conducted on the South Australian Department of Agriculture’s research establishment, Wanbi Agricultural Centre, during the period from March 1991 to September 1994. Wanbi Agricultural Centre is a 1,422 hectare property located in the Northern Mallee region of South Australia, 3 km southwest of the township of Wanbi. The property is divided into 26 main paddocks and is made up of:

- 151 hectares of permanent pasture
- 55 hectares of scrub
- 1,186 hectares available for a crop/grazing rotation
- 30 hectares for miscellaneous use

3.1.1.b Environment:

Wanbi Agricultural Centre is classified as a “semi arid” farming system, ideally suited to low intensity cereal and grazing livestock production. On an annual basis, the seasonal conditions and rainfall pattern at Wanbi result in a normal farming system that incorporates an early spring flush of feed and a period of minimal paddock feed availability during late autumn. The region is considered to experience a yearly drought during summer and autumn.
3.1.1.c Rainfall:

The mean annual rainfall at Wanbi township is 300mm. The majority of the rainfall occurs during the growing season months of April to September. Interpretation of 37 years of detailed weather records maintained at Wanbi Agricultural Centre from the early 1950's until December 1993, shows that the median annual rainfall was 294mm, with a median growing season rainfall of 213mm.

Table: 3.1.1
ANNUAL RAINFALL RECORDED AT WANBI AGRICULTURAL CENTRE DURING THE CONDUCT OF THE FIELD TRIAL

<table>
<thead>
<tr>
<th>YEAR</th>
<th>RAINFALL</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>231mm</td>
<td>March - birth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>September - 6 month shearing</td>
</tr>
<tr>
<td>1992</td>
<td>569mm</td>
<td>March - 12 month shearing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>September 18 month shearing</td>
</tr>
<tr>
<td>1993</td>
<td>287mm</td>
<td>September - 30 month shearing</td>
</tr>
<tr>
<td>1994</td>
<td>186mm</td>
<td>September - 42 month shearing</td>
</tr>
</tbody>
</table>

3.1.1.d Pastures:

Apart from the 151 hectares of permanent pastures (lucerne, perennial veldt grass, evening primrose), the pasture species on the remainder of the property consist mainly of annual medics and annual grasses (ryegrass, brome grass, silver grass, barley grass). The annual pastures generally supplied green forage for the sheep during the period from April to September each year, with dry annual pasture residues being available between October and March.
Forage availability from permanent pastures extended from late August until April. Grazing of cereal stubble residues provided a limited source of forage from late December until mid February in each of the years. As pasture forage quality and availability was insufficient to sustain livestock growth during the period from mid April until late May each year, the nutritional requirements of the trial sheep had to be heavily supplemented with hay and cereal grain. This supplementary feeding consisted of an average quantity of 0.3 kilograms of barley or oats plus 1.0 kilogram of hay per head per day fed for a period of 75 days.

3.1.2 SHEEP

3.1.2.a Breed and bloodline:

The sheep used for the field trial were 205 “Gum Hill” bloodline Medium wool South Australian Merino ewes. Founded in 1885, “Gum Hill” was originally established using animals sourced from the foundation South Australian Merino bloodlines of “Mount Crawford”, “Cappeede”, “North Bungaree”, “Anama” and “Bungaree”, plus the Western Australian “Bungaree” based poll bloodline of “Mulureen”.

Despite the “Gum Hill” bloodline being conducted as a closed flock utilising objective selection techniques since the early 1960’s, its breeding background places it in the “Bungaree” group of the South Australian strong wool Merino.
3.1.2.b Age:

The sheep were born over a period of four weeks during March, 1991. Their sires and dams were of mixed ages. Initial measurements were undertaken while the animals were an average age of six months and continued on a regular basis until the animals were an average age of 42 months.

3.1.2.c Selection:

Apart from some initial light culling of lambs, the sheep were not subjected to any form of selection or culling throughout the period of the experiment. As the trial design simulated the husbandry practices of South Australian sheep flocks, no attempt was made to initially identify the animals as single or multiple born.

3.1.2.d Husbandry:

All the sheep underwent similar husbandry and management practices before and during the period of the experimental measurements. They were subjected to the practices of mulesing, tailing, ear tagging and vaccination at marking. Weaning from their dams occurred at an average age of 20 weeks and they received a booster vaccination and an initial drench.
Heavy supplementary feeding with hay and cereal grain was provided each autumn during the period of the experiment. Sheep were lightly crutched mid-season and jetted with blowfly control chemicals. Drenching was conducted twice each year during the summer period and protective booster vaccinations against clostridial diseases were given annually during March.

3.2 METHODS

3.2.1 Field Trial Phase:

3.2.1.a Animal Identification and Data Recording:

At the commencement of the trial, all animals were permanently identified with dual individually numbered coloured plastic tags placed in each ear. Standardised recording sheets listing the animals in numerical order were drawn up. The sheets were used to record data, quickly detect duplicated measurements and other sampling errors, as well as identify missing animals.

Numbered cards were used to identify fleeces and mid-side samples during operations within the shearing shed.

3.2.1.b Traits Measured:

During the field trial, the following traits were measured:

- greasy fleece weight
- off-shears body weight
3.2.1.c Shearing:

In order to comply with normal industry practice, shearing occurred at the following times:

- September 1991 - 6 months of age (6 months wool growth)
- March 1992 - 12 months of age (6 months wool growth)
- September 1992 - 18 months of age (6 months wool growth)
- September 1993 - 30 months of age (12 months wool growth)
- September 1994 - 42 months of age (12 months wool growth)

On each occasion, shearing was completed within a single four-run day and any minor differences between the technique and skills of individual shearers were felt to be of no consequence in relation to the trial.

3.2.1.d Mid-side Sampling:

A mid-side sample of greasy wool weighing approximately 80 grams was removed from the fleece during shearing. The site of the mid-side sample was identified and marked immediately prior to shearing. To ensure an accurate representative sample was taken from each sheep, the mid-side site was identified using the technique described by Fleet et al. (1988).
This described the mid-side site as being at the third-last rib, halfway between the mid line of the back and the mid-line of the belly on the off-side of the animal. Once the mid-side site had been identified on each animal, a small spot of scourable "sire-sine" spray stock raddle was applied at skin level.

The mid-side sample was removed from the fleece on the board as each shearer completed the final blows on the "whipping" side and exposed the raddled cut-side of the fleece.

During shearing, the sheep number was also verified and recorded on a card that accompanied the mid-side sample. The mid-side sample and identification card were placed in a sealed plastic bag in order to maintain the integrity and uniform moisture content of the sample.

3.2.1.e Fleece Weighing:
Immediately following shearing of the individual animals, the unskirted fleece plus belly and mid-side sample were weighed on an elevated pan scale, prior to the fleece being thrown on the wool table for skirting. Fleece weights were recorded to the nearest 100 grams.

3.2.1.f Body Weighing:
Using electronic scales, body weighing of the sheep was conducted post-shearing.
An interval of seven days in the paddock permitted the sheep to overcome any temporary weight fluctuation due to the prolonged yarding and draining period associated with the previous shearing process. On the day prior to body weighing, the sheep were walked in from the paddock and yarded overnight for a period of approximately fourteen hours without feed or water to minimise differences caused by gut fill.

3.2.2 LABORATORY ANALYSIS PHASE:

3.2.2.a Traits Measured:

Laboratory testing of the mid-side wool sample and analysis of GFW resulted in the measurement of the following traits:

- mean fibre diameter
- clean fleece weight
- Woolplan index calculations

3.2.2.b Wool Testing:

Due to a limited availability of wool testing laboratory facilities, a number of sites were utilised for the conduct of various aspects of the testing procedure:

- Sub-sampling, scouring, oven-dry yield
  - Roseworthy Campus
- Carding
  - Marleston TAFE College
- Conditioning, micron testing
  - Waite Campus
3.2.2.c Scouring:

Scouring of the wool samples to remove dirt, grease and suint was undertaken in preparation for the assessment of oven-dry washing yield. The 80 gram mid-side wool samples collected in the shearing shed were sub-sampled to remove approximately 35 grams direct from the sealed plastic bag. Cloth scour identification number tags were placed with each sample and these remained as the source of identification throughout the wool testing procedure.

The samples were subjected to a wool scouring procedure through a series of four water-filled 82 litre bowls containing the following:

- **Bowl #1** - water 52-54°C, 125 ml Lissapol TN450 detergent
- **Bowl #2** - water 50-52°C, 120 ml Lissapol TN450 detergent
- **Bowl #3** - water 50-52°C, 120 ml Lissapol TN450 detergent
- **Bowl #4** - water 41-43°C, no detergent

Lissapol TN450 is a nonionic surfactant detergent of the alkylphenol ethoxylate class, specifically optimised for natural textile scouring. Each sample was placed in the first scour bowl tip down and gently agitated for a period of four minutes prior to being placed through a mangle-type wringer and immersed in the second scour bowl for a further four minute period. This procedure was repeated as the sample passed through the third and fourth scour bowls.
The fluid in the first scour bowl was recharged with fresh water and Lissapol TN450 woolscour detergent after every 20 samples, while the second and third scour bowls were recharged after every 30 samples. Recharging of the fourth scour bowl with fresh water occurred after every 20 samples.

3.2.2.d Oven dry yield testing:

Determination of the oven-dry washing yield is a prerequisite for the calculation of the clean fleece weight of the animals.

Following removal from the fourth scour bowl and being squeezed-dry through the final wringer, the wool samples were placed flat in individual mesh-bottom metal drying trays. The trays were then placed in a 48 compartment E.S. Ward forced-draught circulation wool drying oven set at 83°C for 45 minutes. Following the period of drying, oven-dry wool weights were obtained by immediately placing the hot wool samples onto a set of electronic scales positioned directly adjacent to the oven.

The use of rubber gloves and metal tongs coupled with rapid weight recording of the hot wool, prevented moisture regain in the sample.

The yield calculation was:

\[
Equation: 3.2.2.1. \text{ Wool Yield Calculation} \\
\text{Wool Yield} = (\text{Oven dry scoured wool weight} + \text{Greasy wool weight}) \times 100
\]
3.2.2.e Carding:

Carding was conducted using a Shirley Analyser. This machine has a carding action which ensures that the fibres are parallel and the wool sample is opened up and mixed as a homogenous blend. It also removes vegetable matter. Approximately 20 grams of wool was removed at random from each scoured sample and cut into lengths of 20 mm.

The wool was slightly dampened with a water spray and fed directly into the Shirley Analyser, resulting in approximately 15 grams of carded wool for further testing. Carding of the sample through the Shirley Analyser occurred in an air conditioned environment maintained with an atmosphere of about 20°C and 60-70% relative humidity, as recommended by the International Wool Secretariat (1986).

3.2.2.f Determination of mean fibre diameter:

Mean fibre diameter was determined using a constant pressure Airflow Apparatus, using the technique specified by the International Wool Secretariat (1986). The carded wool samples were placed in individual plastic baskets, loosley stored within a testing room constantly maintained at standard atmospheric conditions of 65 ± 2% relative humidity and 20 ± 2°C temperature. Samples were stored under the standard atmospheric conditions for a period of at least 48 hours prior to testing in the Airflow Apparatus.
This Airflow Apparatus was calibrated by an accredited laboratory in standard atmospheric conditions using Shirley Analysed standard samples. Throughout the testing procedure, a number of reference samples were re-tested at regular intervals to monitor the calibration accuracy of the Airflow Apparatus.

Two individual test specimens, each weighing 2.5 grams ± 4mg, were drawn from each individual wool sample.

The two test specimens were each tested twice, to provide four discrete fibre diameter readings which were averaged to provide data reflecting the average fibre diameter. Where the range of the four readings exceeded 0.3μm, a further test specimen weighing 2.5 grams ± 4mg was selected from the sample and the average fibre diameter was then based on the average of six readings.

3.2.3 STATISTICAL ANALYSIS:

3.2.3.a Traits analysed:

- Clean fleece weight
- Greasy fleece weight
- Body weight
- Average fibre diameter
- Woolplan Index #1 (C.F.W.)
The Woolplan selection index scores were calculated according to the methodology outlined by Gifford et al. (1992b) and in Maxwell and Brien (1988). Two separate index calculations (Greasy Fleece Weight and Clean Fleece Weight) were analysed for each of the four standard Woolplan breeding objective options.

The Woolplan breeding objective options were:

Option #1  Slight emphasis on reducing F.D.  (5% assumed micron premium)
Option #2  F.D. maintained at current flock level  (1-2% assumed micron premium)
Option #3  Moderate emphasis on reducing F.D.  (10% assumed micron premium)
Option #4  Strong emphasis on reducing F.D.  (20% assumed micron premium)

For each of the Woolplan breeding objective options used, the standard set of traits were:

- Clean fleece weight (or Greasy fleece weight)
- Fibre diameter
- Reproductive rate
- Sale weight of surplus offspring (hogget body weight)
- Culled-for-age weight (mature body weight)

Apart from two values, the assumed phenotypic and genetic parameters used in the Woolplan calculations are the same as reported by Ponzoni (1987). The two exceptions are the phenotypic variances of greasy fleece weight and of fibre diameter, and these two values are cited by Ponzoni (1988).

Although reproduction rate was not recorded in this trial, it was still able to be utilised in the breeding objective because of the existing standard values for the genetic links with other measured traits.

3.2.3.b Analyses conducted:
- Phenotypic Correlation of trait between each age of measurement and adult performance
- Phenotypic Correlation of trait between adjacent measurement ages.
- Estimated Repeatability of the trait
  Standard Error of Estimated Repeatability
- Arithmetic Mean of trait at each age of measurement
- Standard Deviation of trait at each age of measurement
- Coefficient of Variation of trait at each age of measurement
- Accuracy of Producing Ability estimate for the trait
3.2.3.c Adult Performance:

The Adult Performance of an animal in relation to any trait is defined as the average of the measured performance of the trait in that animal at age 30 months and 42 months.

Equation: 3.2.3.1. Adult Performance

\[ AP = \frac{R_{30} + R_{42}}{2} \]

where

- \( AP \) = Adult Performance
- \( R_{30} \) = Record at 30 months of age
- \( R_{42} \) = Record at 42 months of age

3.2.3.d Statistical analysis of data:

Calculation of simple correlations between trait measurements at adjacent ages and correlations between measurements at an individual age & adult performance, were conducted using Microsoft® Excel (1993).

The mean square data used in the computation of repeatability estimates was calculated using Genstat 5 (1992).
3.2.3. e Arithmetic Mean:

Calculation of the arithmetic mean of each data set collected at individual ages was conducted using Microsoft® Excel (1993).

The formula used was:

\[
\bar{Y} = \frac{\sum_{s=1}^{m} \sum_{i=1}^{n_s} y_{is}}{n_y}
\]

where

- \( \bar{Y} \) = Arithmetic Mean of data set Y
- \( s \) = series number
- \( i \) = point number in series \( s \)
- \( m \) = number of series for point \( y \)
- \( n \) = number of points in each series
- \( y_{is} \) = data value of series \( s \) and the \( i^{th} \) point
- \( n_y \) = total number of data values in all series
3.2.3.f Standard Deviation:

Calculation of the standard deviation of each data set collected at individual ages was conducted using Microsoft® Excel (1993).

The formula used was:

\[ \sigma_y = \sqrt{\frac{\sum_{s=1}^{m} \sum_{i=1}^{n} (y_{is} - \bar{Y})^2}{n_y - 1}} \]

where

- \( \sigma_y \) = Standard Deviation of data set Y
- \( \bar{Y} \) = Arithmetic Mean of data set Y
- \( s \) = series number
- \( i \) = point number in series \( s \)
- \( m \) = number of series for point \( y \)
- \( n \) = number of points in each series
- \( y_{is} \) = data value of series \( s \) and the \( i^{th} \) point
- \( n_y \) = total number of data values in all series
3.2.3.9 Coefficient of Variation:

Calculation of the coefficient of variation of each data set collected at individual ages was conducted using the following formula:

\[
C.V. = \frac{\sigma_y}{\bar{y}} \times 100
\]

where

- \( C.V. \) = Coefficient of Variation
- \( \sigma_y \) = Standard Deviation of data set \( Y \)
- \( \bar{y} \) = Arithmetic Mean of data set \( Y \)

3.2.3.h Phenotypic Correlation:

The phenotypic correlation coefficient was estimated by the division of the covariance of the two data sets by the product of their standard deviations.

The formula used was:
Equation: 3.2.3.5. Phenotypic Correlation

\[ \rho_{x,y} = \frac{\text{Cov}(X,Y)}{\sigma_x \cdot \sigma_y} \]

where \[ \text{Cov}(X,Y) = \frac{1}{n-1} \sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y}) \]

and \[ \sigma_x^2 = \frac{1}{n-1} \sum (X_i - \bar{X})^2 \]

and \[ \sigma_y^2 = \frac{1}{n-1} \sum (Y_i - \bar{Y})^2 \]

\[ \rho_{x,y} = \text{Correlation coefficient of data sets X & Y} \]

\[ \text{Cov}(X,Y) = \text{Covariance of data sets X & Y} \]

\[ n = \text{number of individuals} \]

\[ X_i = \text{individual measurements in data set X} \]

\[ \bar{X} = \text{mean of all measurements in data set X} \]

\[ Y_i = \text{individual measurements in data set Y} \]

\[ \bar{Y} = \text{mean of all measurements in data set Y} \]

\[ \sigma_x = \text{standard deviation of data set X} \]

\[ \sigma_y = \text{standard deviation of data set Y} \]
3.2.3.1 Estimated Repeatability:

The repeatability estimates for the traits were derived using variance components.

The variance components are generated from an analysis of variance following the method of Becker (1985) as shown below:

**Equation: 3.2.3.6. Analysis of Variance**

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>SS</th>
<th>MS</th>
<th>EMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between individuals</td>
<td>$N - 1$</td>
<td>$SS_w$</td>
<td>$MS_w$</td>
<td>$\sigma_e^2 + k_1\sigma_w^2$</td>
</tr>
<tr>
<td>Between measurements</td>
<td>$N - 1(M - 1)$</td>
<td>$SS_E$</td>
<td>$MS_E$</td>
<td>$\sigma_E^2$</td>
</tr>
<tr>
<td>within individuals</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

where

$N$ = number of individuals

$M$ = number of measurements per individual; equal number for each individual

$k_1 = M$

$MS_E$ = Mean Square of residual

$MS_w$ = Mean Square of individual sheep

$\sigma_w^2$ = variance between individual sheep

$\sigma_E^2$ = variance within sheep
Since the traits in this study (e.g., body weight, fleece weight and fibre diameter) all change as animals age, this change was accounted for in the analysis of variance. Thus, age was fitted before sheep (between animals). This accounts for \((M - 1)\) degrees of freedom (5 ages - 1 = 4 d.f.), so the residual degrees of freedom are \((N - 1)(M - 1)\) and not \(N(M - 1)\). In this study, \(N\) is large (205) compared to \(M\) (5), so the residual mean square does not differ greatly by changing the denominator degrees of freedom. It was not necessary to fit age as part of the model for the Woolplan indices because the mean of all the indices was 100 at each age (by definition).

Estimated repeatability was calculated from the variance components according to Becker (1985):
Equation: 3.2.3.7. Estimated Repeatability

\[ MS_E = V_{TE} \]
\[ MS_w = V_{TE} + k(V_A + V_D + V_I + V_{PE}) \]
\[ t = \frac{\hat{\sigma}^2_w}{\hat{\sigma}^2_w + \hat{\sigma}^2_E} \]

where

- \( t \) = Repeatability
- \( MS_E \) = Mean Square of residual
- \( MS_w \) = Mean Square of individual sheep
- \( V_A \) = Additive variance
- \( V_D \) = Dominance variance
- \( V_I \) = Epistatic variance
- \( V_{PE} \) = Permanent environmental variance
- \( V_{TE} \) = Temporary environmental variance
- \( k \) = number of records for each sheep
- \( \hat{\sigma}^2_w \) = variance between individual sheep
- \( \hat{\sigma}^2_w \) = variance within sheep
3.2.3.j Standard Error of Repeatability:

The standard error of estimated repeatability was calculated according to the method described by Becker (1985). This calculation is the square root of the sampling variance of the intraclass correlation, $\tau$.

**Equation: 3.2.3.8. Standard Error of Repeatability Estimates**

$$S.E.(t) = \sqrt{\frac{2(1-t)^2}{k(k-1)\tau^2}} \frac{1}{(N-1)}$$

where

- $S.E.(t)$ = Standard Error of Repeatability Estimate
- $t$ = Repeatability
- $k$ = number of records for each sheep
- $N$ = number of individuals
3.2.3.k Accuracy of Producing Ability estimate:

Producing Ability is a measure of the level of accuracy attributed to the repeatability estimate, accorded by the number of records used to determine the estimate.

\[
PA = \frac{kt}{1 + (k - 1)t} (X - \overline{X})
\]

where

\[
\begin{align*}
PA & = \text{Producing Ability} \\
k & = \text{number of records} \\
t & = \text{repeatability} \\
X & = \text{measured record of the individual's trait} \\
\overline{X} & = \text{mean of the group for the recorded trait}
\end{align*}
\]

The Accuracy of Producing Ability is a measure to predict the effect on the accuracy of the repeatability estimate, produced by the inclusion of an increasing number of repeated measurements of a trait.
Equation: 3.2.3.10. Accuracy of Producing Ability

$$APA = \sqrt{\frac{kt}{1 + (k - 1)t}}$$

where

- $APA$ = Accuracy of Producing Ability
- $k$ = number of records
- $t$ = repeatability
4. RESULTS:

4.1 Fleece and Body Characters and Woolplan Indices:

Measured fleece and body characters at each age are presented in Table 4.1.1. Pair wise comparisons of least square means based on T-tests for each of the measured traits showed that measurements at each age were significantly different from measurements at other ages (P<0.001). Across the study, the average body weight increased from 25 kg at the 6 month measurement, to 68 kg at the 42 month measurement. Average greasy fleece weight ranged from 1.5 kg (6 months growth) at the 6 month measurement, to 6.7 kg (12 months growth) at the 30 month measurement. The range of average clean fleece weight was from 0.9 kg (6 months growth) at the 6 month measurement, to 4.1 kg (12 months growth) at the 30 month measurement. Mean fibre diameter ranged from 20.7 microns at the 6 month measurement, to 23.6 microns at the 42 month measurement.

Table: 4.1.1.
MEAN AND STANDARD DEVIATION OF CHARACTERS OF SOUTH AUSTRALIAN MERINO SHEEP AT EACH MEASUREMENT AGE

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>6 months</th>
<th>12 months</th>
<th>18 months</th>
<th>30 months</th>
<th>42 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Weight (kg)</td>
<td>25 a</td>
<td>33 b</td>
<td>51 c</td>
<td>57 d</td>
<td>68 e</td>
</tr>
<tr>
<td></td>
<td>(3.4)</td>
<td>(3.5)</td>
<td>(5.2)</td>
<td>(5.5)</td>
<td>(6.1)</td>
</tr>
<tr>
<td>Greasy Fleece Wt. (kg)</td>
<td>1.5 a</td>
<td>3.4 b</td>
<td>4.1 c</td>
<td>6.7 d</td>
<td>6.5 e</td>
</tr>
<tr>
<td></td>
<td>(0.4)</td>
<td>(0.5)</td>
<td>(0.4)</td>
<td>(0.7)</td>
<td>(0.7)</td>
</tr>
<tr>
<td>Clean Fleece Wt. (kg)</td>
<td>0.9 a</td>
<td>1.8 b</td>
<td>2.4 c</td>
<td>4.1 d</td>
<td>3.8 e</td>
</tr>
<tr>
<td></td>
<td>(0.2)</td>
<td>(0.3)</td>
<td>(0.3)</td>
<td>(0.5)</td>
<td>(0.4)</td>
</tr>
<tr>
<td>Fibre Diameter (micron)</td>
<td>20.7 a</td>
<td>22.8 b</td>
<td>22.3 c</td>
<td>21.2 d</td>
<td>23.6 e</td>
</tr>
<tr>
<td></td>
<td>(1.4)</td>
<td>(1.6)</td>
<td>(1.7)</td>
<td>(1.6)</td>
<td>(1.9)</td>
</tr>
</tbody>
</table>

* Superscripts imply means differ at each age (P<0.001)
Because of the method of calculation of the Woolplan selection indices, the mean index figure at each measurement age was exactly 100 (Table: 4.1.2.) and thus there were no differences between ages.

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>6 months</th>
<th>12 months</th>
<th>18 months</th>
<th>30 months</th>
<th>42 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woolplan #1 (CFW)</td>
<td>11.7</td>
<td>12.1</td>
<td>11.1</td>
<td>11.4</td>
<td>11.8</td>
</tr>
<tr>
<td>Woolplan #1 (GFW)</td>
<td>9.4</td>
<td>10.0</td>
<td>9.4</td>
<td>9.4</td>
<td>10.5</td>
</tr>
<tr>
<td>Woolplan #2 (CFW)</td>
<td>10.3</td>
<td>9.7</td>
<td>9.4</td>
<td>9.6</td>
<td>9.5</td>
</tr>
<tr>
<td>Woolplan #2 (GFW)</td>
<td>8.0</td>
<td>7.2</td>
<td>7.0</td>
<td>7.1</td>
<td>7.2</td>
</tr>
<tr>
<td>Woolplan #3 (CFW)</td>
<td>10.9</td>
<td>12.3</td>
<td>11.2</td>
<td>11.1</td>
<td>12.2</td>
</tr>
<tr>
<td>Woolplan #3 (GFW)</td>
<td>9.8</td>
<td>11.3</td>
<td>10.6</td>
<td>10.3</td>
<td>11.9</td>
</tr>
<tr>
<td>Woolplan #4 (CFW)</td>
<td>10.4</td>
<td>12.0</td>
<td>11.3</td>
<td>10.8</td>
<td>12.3</td>
</tr>
<tr>
<td>Woolplan #4 (GFW)</td>
<td>10.0</td>
<td>11.7</td>
<td>11.1</td>
<td>10.5</td>
<td>12.3</td>
</tr>
</tbody>
</table>

Apart from greasy fleece weight and mean fibre diameter, the coefficient of variation for fleece and body characters developed a similar trend at each measurement age (Figure: 4.1.1.).
From 6 months to 42 months of age, the coefficient of variation for mean fibre diameter followed a reverse trend to the other three characters. However at all ages of measurement the coefficient of variation for mean fibre diameter remained below that of the other characters.

**Figure: 4.1.1.**

At the 6 month measurement age, the coefficient of variation for the various measured characters extended over a very wide range. The variation extended from 26.7 per cent for greasy fleece weight down to 6.8 per cent for mean fibre diameter. However by the 42 month measurement age, all characters had coefficient of variation values that were in the very narrow range of 8.1 to 10.8 per cent.
Woolplan selection indices at each measurement age are presented in Table 4.1.2. The CFW (Figure: 4.1.2.) and GFW (Figure: 4.1.3.) options for Woolplan indices #1, #3 and #4 all followed a similar stable trend line for coefficient of variation at each measurement age. However the GFW and CFW options for Woolplan index #2 consistently recorded a lower coefficient of variation at each measurement age than the other indices. Woolplan index #2 breeding objective is to maintain fibre diameter at the current flock level, with a low assumed micron premium of 1-2 per cent.

Figure: 4.1.2.
4.2 Phenotypic Correlation between adjacent Measurement Ages:

Phenotypic correlations of single characters between adjacent measurement ages are presented in Table 4.2.1. The phenotypic correlation between the rankings of physical measurements taken at ages 6 months and 12 months was relatively high for body weight and mean fibre diameter, with coefficients of 0.73 and 0.66 respectively (Figure: 4.2.1.). For the same age comparison, greasy fleece weight had a medium phenotypic correlation coefficient of 0.56, while clean fleece weight had an extremely low phenotypic correlation coefficient of 0.32.
Table: 4.2.1.
PHENOTYPIC CORRELATION OF SINGLE CHARACTERS BETWEEN ADJACENT MEASUREMENT AGES IN SOUTH AUSTRALIAN MERINO SHEEP

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>6 months Vs 12 months</th>
<th>12 months Vs 18 months</th>
<th>18 months Vs 30 months</th>
<th>30 months Vs 42 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Weight</td>
<td>0.73</td>
<td>0.73</td>
<td>0.80</td>
<td>0.89</td>
</tr>
<tr>
<td>Greasy Fleece Weight</td>
<td>0.56</td>
<td>0.72</td>
<td>0.72</td>
<td>0.76</td>
</tr>
<tr>
<td>Clean Fleece Weight</td>
<td>0.32</td>
<td>0.39</td>
<td>0.41</td>
<td>0.54</td>
</tr>
<tr>
<td>Fibre Diameter</td>
<td>0.66</td>
<td>0.73</td>
<td>0.77</td>
<td>0.74</td>
</tr>
</tbody>
</table>

When the 12 month and 18 month measurement rankings were compared, the phenotypic correlation coefficient of mean fibre diameter increased to 0.73. The correlation coefficient of this comparison was of a similar magnitude to that of body weight (0.73) and greasy fleece weight (0.72).

Tests were conducted to detect differences between the correlations of adjacent ages of measurement, using a T-test with a pooled standard error. Although the phenotypic correlation of clean fleece weight at this stage also increased, its value of 0.39 was still far lower than other measured characters. For mean fibre diameter, the increase between the 6 month Vs 12 month correlation coefficient (0.66) and the 12 month Vs 18 month correlation coefficient (0.73) was highly significant (P<0.01). While there was no significant difference for body weight between these two comparisons, the increase for greasy fleece weight was also highly significant (P<0.001). Clean fleece weight had a moderately significant increase in the phenotypic correlation coefficient (P<0.01).
Phenotypic correlations for body weight, clean fleece weight and mean fibre diameter all increased when the 18 month measurement rankings were compared with the 30 month measurement rankings. This increase in correlation coefficient was significant for body weight and mean fibre diameter (BW - P<0.001, FD - P<0.05). The correlation coefficient of 0.80 for body weight was the highest of all measured characters at this stage. The phenotypic correlation for body weight, greasy fleece weight and for mean fibre diameter were all comparatively high at the final assessment stage. However, although the phenotypic correlation between adjacent ages for clean fleece weight continued to increase at the latter age comparison (P<0.001), the correlation coefficient of 0.54 was still only in the medium range.
Phenotypic correlations of Woolplan selection indices between adjacent measurement ages are presented in Table 4.2.2. At each stage of assessment, phenotypic correlation coefficients between adjacent measurement ages for the C.F.W. Woolplan indices remained below that of the corresponding G.F.W. Woolplan indices. The four C.F.W. indices had phenotypic correlation coefficients ranging from 0.46 to 0.66 at the 6 month Vs 12 month assessment, while the corresponding G.F.W. indices had a range of coefficients from 0.68 to 0.70 at the same stage.

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>6 months Vs 12 months</th>
<th>12 months Vs 18 months</th>
<th>18 months Vs 30 months</th>
<th>30 months Vs 42 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woolplan #1 (CFW)</td>
<td>0.54</td>
<td>0.63</td>
<td>0.63</td>
<td>0.74</td>
</tr>
<tr>
<td>Woolplan #1 (GFW)</td>
<td>0.70</td>
<td>0.76</td>
<td>0.78</td>
<td>0.84</td>
</tr>
<tr>
<td>Woolplan #2 (CFW)</td>
<td>0.46</td>
<td>0.50</td>
<td>0.51</td>
<td>0.64</td>
</tr>
<tr>
<td>Woolplan #2 (GFW)</td>
<td>0.69</td>
<td>0.74</td>
<td>0.77</td>
<td>0.84</td>
</tr>
<tr>
<td>Woolplan #3 (CFW)</td>
<td>0.62</td>
<td>0.72</td>
<td>0.74</td>
<td>0.78</td>
</tr>
<tr>
<td>Woolplan #3 (GFW)</td>
<td>0.69</td>
<td>0.76</td>
<td>0.78</td>
<td>0.80</td>
</tr>
<tr>
<td>Woolplan #4 (CFW)</td>
<td>0.66</td>
<td>0.75</td>
<td>0.78</td>
<td>0.77</td>
</tr>
<tr>
<td>Woolplan #4 (GFW)</td>
<td>0.68</td>
<td>0.75</td>
<td>0.77</td>
<td>0.76</td>
</tr>
</tbody>
</table>
Apart from the two Woolplan index #2 options (Table: 4.2.2.), the increase in phenotypic correlation coefficients of the C.F.W. and G.F.W. Woolplan indices between the 6 month Vs 12 month and the 12 month Vs 18 month comparisons was highly significant (P<0.001). The increase in correlation coefficient for each of the Woolplan indices at the next comparison stage was not significant. At the final 30 month Vs 42 month comparison stage, the phenotypic correlation coefficients of the C.F.W. Woolplan index #4 (Figure: 4.2.2.) and the G.F.W. Woolplan index #4 (Figure: 4.2.3.) showed a non significant downward trend. The phenotypic correlation coefficient for the C.F.W. Woolplan index #2 remained in the medium range at each measurement age comparison.

Figure: 4.2.2.

**Correlations of Woolplan (CFW) Indices Between Adjacent Ages of Measurement**

[Graph showing correlation coefficients between Woolplan indices at different ages]
4.3 Phenotypic Correlation of Age of Measurement Vs Adult Performance:

Phenotypic correlations of single characters between age of measurement and adult performance are presented in Table 4.3.1. Tests were conducted to detect differences between the correlations of "age of measurement Vs adult performance", using a T-test with a pooled standard error. Measurement of body weight and mean fibre diameter at 6 months of age provided a medium level of phenotypic correlation with adult performance (0.56 and 0.58 respectively). At this age, clean fleece weight had a very low phenotypic correlation of 0.17, while greasy fleece weight had a slightly higher phenotypic correlation of 0.30 (Figure: 4.3.1.). This phenotypic correlation for greasy fleece weight was relatively low.
The second assessment of measurement rankings at the age of 12 months produced high phenotypic correlations in the 0.63 - 0.77 range for all physically measured characters apart from clean fleece weight. The increase at this age was moderately significant for fibre diameter (P<0.01), but highly significant for all other measured characters (P<0.001). The high phenotypic correlation coefficients were maintained for body weight, greasy fleece weight and fibre diameter at successive measurement ages. However, the phenotypic correlation coefficient for clean fleece weight remained in the low to medium range until the 30 month measurement age when it reached 0.89. This high coefficient was expected because of the innate definition of "adult performance" (average of the 30 month and the 42 month performances). The increase in the phenotypic correlation coefficient for clean fleece weight at each stage leading to the 30 month measurement was highly significant (P<0.001).

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>6 months Vs Adult</th>
<th>12 months Vs Adult</th>
<th>18 months Vs Adult</th>
<th>30 months Vs Adult</th>
<th>42 months Vs Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Weight</td>
<td>0.56</td>
<td>0.76</td>
<td>0.81</td>
<td>0.97</td>
<td>0.98</td>
</tr>
<tr>
<td>Greasy Fleece Weight</td>
<td>0.30</td>
<td>0.63</td>
<td>0.81</td>
<td>0.94</td>
<td>0.93</td>
</tr>
<tr>
<td>Clean Fleece Weight</td>
<td>0.17</td>
<td>0.39</td>
<td>0.55</td>
<td>0.89</td>
<td>0.87</td>
</tr>
<tr>
<td>Fibre Diameter</td>
<td>0.58</td>
<td>0.77</td>
<td>0.76</td>
<td>0.92</td>
<td>0.94</td>
</tr>
</tbody>
</table>
Phenotypic correlation coefficients of Woolplan selection indices between age of measurement and adult performance are presented in Table 4.3.2. In general, the C.F.W. option for all Woolplan indices had a lower phenotypic correlation coefficient than the corresponding G.F.W. option. There were several occasions when this relativity did not apply, however the differences were not significant. At the 6 month measurement age, phenotypic correlation coefficients of the C.F.W. options for Woolplan indices #1 and #2 were very low, being 0.37 and 0.23 respectively (Figure: 4.3.2.). The C.F.W. options for Woolplan indices #3 and #4 had higher phenotypic correlation coefficients of 0.51 and 0.58 respectively.
Table: 4.3.2.

SELECTION INDICES PHENOTYPIC CORRELATION OF AGE OF MEASUREMENT Vs ADULT PERFORMANCE IN SOUTH AUSTRALIAN MERINO SHEEP

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>6 months Vs Adult</th>
<th>12 months Vs Adult</th>
<th>18 months Vs Adult</th>
<th>30 months Vs Adult</th>
<th>42 months Vs Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woolplan #1 (CFW)</td>
<td>0.37</td>
<td>0.56</td>
<td>0.73</td>
<td>0.93</td>
<td>0.93</td>
</tr>
<tr>
<td>Woolplan #1 (GFW)</td>
<td>0.46</td>
<td>0.73</td>
<td>0.82</td>
<td>0.95</td>
<td>0.96</td>
</tr>
<tr>
<td>Woolplan #2 (CFW)</td>
<td>0.23</td>
<td>0.45</td>
<td>0.63</td>
<td>0.91</td>
<td>0.91</td>
</tr>
<tr>
<td>Woolplan #2 (GFW)</td>
<td>0.37</td>
<td>0.65</td>
<td>0.82</td>
<td>0.96</td>
<td>0.96</td>
</tr>
<tr>
<td>Woolplan #3 (CFW)</td>
<td>0.51</td>
<td>0.68</td>
<td>0.78</td>
<td>0.94</td>
<td>0.95</td>
</tr>
<tr>
<td>Woolplan #3 (GFW)</td>
<td>0.55</td>
<td>0.77</td>
<td>0.80</td>
<td>0.94</td>
<td>0.96</td>
</tr>
<tr>
<td>Woolplan #4 (CFW)</td>
<td>0.58</td>
<td>0.75</td>
<td>0.79</td>
<td>0.93</td>
<td>0.95</td>
</tr>
<tr>
<td>Woolplan #4 (GFW)</td>
<td>0.58</td>
<td>0.78</td>
<td>0.78</td>
<td>0.93</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Figure: 4.3.2.

CORRELATIONS OF WOOLPLAN (CFW) INDICES
AGE OF MEASUREMENT Vs ADULT PERFORMANCE

AGE OF MEASUREMENT (months) Vs ADULT PERFORMANCE

CORRELATION COEFFICIENT

6 m 12 m 18 m 30 m 42 m
Vs Vs Vs Vs Vs
Adult Adult Adult Adult Adult
At the 12 month measurement age, phenotypic correlation of the C.F.W. options for Woolplan indices #1 and #2 increased significantly to the medium range of 0.56 and 0.45 respectively (P<0.001). At this age, the phenotypic correlation coefficients of the C.F.W. options for Woolplan indices #3 and #4 also increased significantly (P<0.001) in the high range of 0.68 and 0.75 respectively. From the 18 month measurement age onward, phenotypic correlations of all C.F.W. Woolplan indices options were considered to be high.

At the 6 month measurement age (Figure: 4.3.3.), phenotypic correlations of the G.F.W. options for Woolplan indices #1 and #2 were 0.46 and 0.37 respectively. These were relatively low compared with the phenotypic correlation values of 0.55 and 0.58 for the G.F.W. options of Woolplan indices #3 and #4. Each of the Woolplan G.F.W. index options experienced a highly significant increase in phenotypic correlation values between the 6 month and 12 month ages (P<0.001). Measurements recorded from the age of 12 months onward produced high phenotypic correlation values for all the G.F.W. Woolplan indices.

The four G.F.W. Woolplan indices started to converge at 18 months with a coefficient approximately 0.80. Apart from the CFW Woolplan index option #2, the various C.F.W. Woolplan indices also started to converge at 18 months, with coefficients in the range 0.73-0.79.
By nature of the definition of “adult performance” (the average of the 30 month and the 42 month measurements) it was not unexpected that the phenotypic correlation coefficients for the 30 month Vs adult and the 42 month Vs adult were extremely high.

**Figure: 4.3.3.**

**CORRELATIONS OF WOOLPLAN (GFW) INDICES**  
**AGE OF MEASUREMENT Vs ADULT PERFORMANCE**

4.4 Estimated Repeatability of Characters:

The estimated repeatabilities of wool production characters are presented in Table 4.4.1. Approximate standard error on these, representing the variation around the repeatability estimate, was 0.03 and each had a significance P<0.001. Body weight and mean fibre diameter had high repeatability estimates of 0.68 and 0.67 respectively. Greasy fleece weight had a medium repeatability estimate of 0.55, while clean fleece weight had a much lower repeatability estimate of 0.33.
Table 4.4.1.
ESTIMATED REPEATABILITY OF MEASURED FLEECE AND BODY CHARACTERS IN SOUTH AUSTRALIAN MERINO SHEEP

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>Repeatability</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Weight</td>
<td>0.68 ***</td>
<td>± 0.026</td>
</tr>
<tr>
<td>Greasy Fleece weight</td>
<td>0.55 ***</td>
<td>± 0.032</td>
</tr>
<tr>
<td>Clean Fleece Weight</td>
<td>0.33 ***</td>
<td>± 0.034</td>
</tr>
<tr>
<td>Fibre Diameter</td>
<td>0.67 ***</td>
<td>± 0.027</td>
</tr>
</tbody>
</table>

*** T-test for differences from zero (P<0.001)

The estimated repeatabilities of Woolplan selection indices are presented in Table 4.4.2. Without exception, the four C.F.W. Woolplan indices options had lower repeatability estimates than the corresponding G.F.W. Woolplan indices options.

The C.F.W. option for Woolplan index #2 had a low repeatability estimate of 0.43, while the C.F.W. option for Woolplan index #1 had a medium repeatability estimate of 0.54. All other Woolplan indices had higher repeatability estimates above 0.60.
### Table 4.4.2.
ESTIMATED REPEATABILITY OF SELECTION INDICES CALCULATED USING SOUTH AUSTRALIAN MERINO SHEEP

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>Repeatability</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woolplan #1 (CFW)</td>
<td>0.54 ***</td>
<td>± 0.032</td>
</tr>
<tr>
<td>Woolplan #1 (GFW)</td>
<td>0.67 ***</td>
<td>± 0.027</td>
</tr>
<tr>
<td>Woolplan #2 (CFW)</td>
<td>0.43 ***</td>
<td>± 0.034</td>
</tr>
<tr>
<td>Woolplan #2 (GFW)</td>
<td>0.62 ***</td>
<td>± 0.029</td>
</tr>
<tr>
<td>Woolplan #3 (CFW)</td>
<td>0.61 ***</td>
<td>± 0.030</td>
</tr>
<tr>
<td>Woolplan #3 (GFW)</td>
<td>0.69 ***</td>
<td>± 0.026</td>
</tr>
<tr>
<td>Woolplan #4 (CFW)</td>
<td>0.68 ***</td>
<td>± 0.026</td>
</tr>
<tr>
<td>Woolplan #4 (GFW)</td>
<td>0.69 ***</td>
<td>± 0.026</td>
</tr>
</tbody>
</table>

*** T-test for differences from zero (P<0.001)

#### 4.5 Accuracy of Producing Ability for each Character:

The accuracy of producing ability for each measured character is presented in Table 4.5.1. Of the measured fleece and body characters, only greasy fleece weight and clean fleece weight failed to provide an accuracy of 75 per cent with the use of one record (Figure: 4.5.1.).

---

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Table: 4.5.1.
ACCURACY OF PRODUCING ABILITY FOR EACH MEASURED CHARACTER IN SOUTH AUSTRALIAN MERINO SHEEP

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>1 record</th>
<th>2 records</th>
<th>3 records</th>
<th>4 records</th>
<th>5 records</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Weight</td>
<td>0.83</td>
<td>0.90</td>
<td>0.93</td>
<td>0.95</td>
<td>0.96</td>
</tr>
<tr>
<td>Greasy Fleece Weight</td>
<td>0.74</td>
<td>0.84</td>
<td>0.89</td>
<td>0.91</td>
<td>0.93</td>
</tr>
<tr>
<td>Clean Fleece Weight</td>
<td>0.58</td>
<td>0.70</td>
<td>0.77</td>
<td>0.81</td>
<td>0.84</td>
</tr>
<tr>
<td>Fibre Diameter</td>
<td>0.82</td>
<td>0.90</td>
<td>0.93</td>
<td>0.94</td>
<td>0.95</td>
</tr>
</tbody>
</table>

When two records were utilised to assess the producing ability of the measured characters, the level of accuracy for clean fleece weight still remained below the 75 per cent threshold, although the level of accuracy for greasy fleece weight did rise to 84 per cent. Two records provided a very high accuracy level of 90 percent for body weight and mean fibre diameter.

Figure: 4.5.1.
While the use of three records to assess the producing ability of clean fleece weight did provide an accuracy above 75 per cent, the relative accuracy of this character remained below that of the other measured characters at each of the record utilisation levels. By its nature, sheep selection always involves a compromise between accuracy of selection and the period that sheep must be retained until selection is undertaken. Because of this, the 75 per cent accuracy benchmark was utilised in this study to simulate actual on-property criteria. As the number of records incorporated in the analysis of each of the measured characters increased, there was a corresponding rise in the level of accuracy. However, the relative rate of gain in accuracy diminished when more than three records were utilised, than when one to three records were included in an assessment of producing ability.

The accuracy of producing ability for each selection indices option is presented in Table 4.5.2. A single record provided an accuracy of producing ability above 75 per cent for the C.F.W. options for Woolplan indices #3 and #4 (Figure: 4.5.2.). However two records were required to provide at least 75 per cent accuracy for the C.F.W. options for Woolplan indices #1 and #2. Of the four C.F.W. options, at each level of record use, Woolplan index #4 always provided the greatest level of accuracy. Listed in the order of descending accuracy levels at each level of record use, were index #3, index #1 and index #2.
Although the level of accuracy continued to rise as the number of records utilised increased, the inclusion of greater than three records provided a decreasing rate of improvement for all C.F.W. Woolplan indices apart from #2. Increasing the number of records used from one to three provided an average improvement in accuracy of 14 per cent. However the inclusion of five records only provided an additional 4 per cent accuracy.

Table: 4.5.2.

ACCURACY OF PRODUCING ABILITY FOR EACH SELECTION INDICES OPTION IN SOUTH AUSTRALIAN MERINO SHEEP

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>1 record</th>
<th>2 records</th>
<th>3 records</th>
<th>4 records</th>
<th>5 records</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woolplan #1 (CFW)</td>
<td>0.74</td>
<td>0.84</td>
<td>0.88</td>
<td>0.91</td>
<td>0.92</td>
</tr>
<tr>
<td>Woolplan #1 (GFW)</td>
<td>0.82</td>
<td>0.90</td>
<td>0.93</td>
<td>0.94</td>
<td>0.95</td>
</tr>
<tr>
<td>Woolplan #2 (CFW)</td>
<td>0.66</td>
<td>0.78</td>
<td>0.83</td>
<td>0.87</td>
<td>0.90</td>
</tr>
<tr>
<td>Woolplan #2 (GFW)</td>
<td>0.79</td>
<td>0.88</td>
<td>0.91</td>
<td>0.93</td>
<td>0.94</td>
</tr>
<tr>
<td>Woolplan #3 (CFW)</td>
<td>0.78</td>
<td>0.87</td>
<td>0.91</td>
<td>0.93</td>
<td>0.94</td>
</tr>
<tr>
<td>Woolplan #3 (GFW)</td>
<td>0.83</td>
<td>0.90</td>
<td>0.93</td>
<td>0.95</td>
<td>0.96</td>
</tr>
<tr>
<td>Woolplan #4 (CFW)</td>
<td>0.83</td>
<td>0.90</td>
<td>0.93</td>
<td>0.95</td>
<td>0.96</td>
</tr>
<tr>
<td>Woolplan #4 (GFW)</td>
<td>0.83</td>
<td>0.90</td>
<td>0.93</td>
<td>0.95</td>
<td>0.96</td>
</tr>
</tbody>
</table>
For index #2, the improvement in accuracy was 7 per cent. The use of a single record provided an accuracy of producing ability above 75 per cent for each of the four G.F.W. Woolplan indices options (Figure: 4.5.3.). Although the level of accuracy for the G.F.W. Woolplan index #2 option was below that of the other G.F.W. options at each record level, the difference was only 2 percentage points below the average accuracy of all the G.F.W. indices. For these four indices, the improvement in level of accuracy provided through the use of two records instead of one was 8 per cent. However, the use of an additional record only provided a further 3 per cent increase in accuracy.
Apart from Woolplan index #4, at each level of record usage the C.F.W. Woolplan index option always provided a lower level of accuracy than the corresponding G.F.W. Woolplan index option. However both the C.F.W. and G.F.W. options for Woolplan index #4 recorded exactly the same level of accuracy.

Figure: 4.5.3.

![ACCURACY OF PRODUCING ABILITY FOR WOOLPLAN (GFW) INDICES](image_url)
5. DISCUSSION:

5.1 Current Practices:

When using objective measurements to select sheep for inclusion in a breeding flock or wool producing enterprise, sheep breeders must reach a necessary compromise between accuracy of selection and the requirement to remove inferior animals from the flock at the earliest possible opportunity. There is continued effort to strike a balance between the attainment of maximum productivity improvement within a flock and the minimisation of costs of production. During the 1950's and 1960's, this selection was generally conducted at an age of 15-16 months with 10-12 months fleece growth (Piper, 1990). However since the 1970's, it has been more common for sheep to be measured at an age of 6-12 months and with 6-8 months wool growth (Ponzoni, 1979a; Atkins, 1987; Atkins and Mortimer, 1987; Rogan et al., 1987).

There is considerable pressure amongst stud breeders to implement the selection procedure at the youngest possible age (Rogan, 1982; Watts, 1992). However with the reduction in age of selection, there has been rising scepticism amongst sheep producers in relation to the ability of performance records to accurately determine the true merit of the animals being measured (McGuirk, 1987b; Metcalfe and Brien, 1992). This lack of confidence by many of the sheep breeding fraternity is one of the major impediments to the efficient selection of Merino sheep and effective use of objective measurements.
The struggle of the Woolplan selection index to achieve widespread acceptance following its launch in the 1980's and its subsequent public demise in 1993, did little to reassure Merino producers that performance measurements and selection indices were reliable aids for sheep breeders. As a result, a real need emerged for the conduct of regional studies on repeatabilities of performance recording data and selection indices (Brien et al., 1991).

The principal role of the study at Wanbi, involving South Australian strong wool Merino sheep, was to establish a greater degree of selection confidence amongst breeders of this type of sheep by demonstrating how regionally-derived repeatability estimates and phenotypic correlations relate to the reliability of their on-property selection practices. While it is doubtful that the results of a single study conducted in a discrete environment will dramatically alter the selection practices of an entire industry, there is no doubt that in the long term, the combined effect of this and a number of similar studies will have a widespread influence.

5.2. Interpretation of the Statistical Analysis:

The formulation of a preferred sheep selection strategy based on the results of the Wanbi trial has been done through an integrated interpretation of a series of four separate analytical “tools”. These “tools” were:

- Analysis of Performance Records Collected;
- Potential for Flock Production Gains through Animal Selection;
- Age of Selection;
- Number of Records Required to Provide Accuracy of Selection.

5.2.1. Analysis of Performance Records Collected:
The analysis of performance records collected was undertaken using the mean, standard deviation and coefficient of variation of the raw data and selection indices.

As the performance measurements recorded on the sheep in this study were done at ages ranging from 6 months to 42 months, it was legitimate to assume that the normal growth patterns of the sheep from weaning until maturity would provide a general increase in greasy fleece weight, clean fleece weight, body weight and fibre diameter. Although this pattern was quite evident during the early life of the animals (see Table: 4.1.1.), it was confounded to some extent at the mature ages of 30 months and 42 months by a greater contrast in between-year seasonal conditions (see Table: 3.1.1.). Because supplementary feeding was kept to a minimum, the yearly rainfall and resulting pasture and cereal stubble availability had an over-riding influence on the productivity of mature sheep.

5.2.2. Potential for Flock Production Gains through Animal Selection:
The potential for flock production gains through animal selection was gauged from the repeatability estimate of each character.
While repeatability estimates do not provide the best indication of the most appropriate age at which sheep should be measured, they do provide evidence of the lifetime production gains that can be made within a flock if selection is applied to the various characters.

A low repeatability estimate for a character may indicate that selection pressure is best diverted to other characters, while high repeatability estimates indicate that large gains are possible through the application of selection pressure for that particular character. Where estimated repeatability is low, the accuracy of the selection may be improved by basing selection on the means of two or more records, while a high repeatability estimate indicates that selection for lifetime production can be based on a single record (Mortimer, 1987; Turner and Young, 1987).

The repeatability estimates reported by the Wanbi trial (0.33 - 0.68) (see Table: 4.4.1. and Table: 4.4.2.) were considered to be in the low to medium range of previously established estimates obtained using various Merino strains and bloodlines (see Tables: 2.4.1.1.; 2.4.1.3.; 2.4.1.5.; 2.4.1.7.). However, these repeatability estimates were significant and were largely in accord with estimates obtained in the few research studies that concentrated on the strong-wool South Australian Merino strain.
5.2.3. Age of Selection:

An assessment of the age of selection of sheep within a flock was undertaken using two measures. These were the phenotypic correlation between adjacent measurement ages and also the phenotypic correlation between age of measurement and adult performance.

While producers are generally aware of the need to delay sheep selection until an age when production measurements provide an accurate estimate of adult performance, there is also a requirement to ensure that this age is kept to a minimum. Retention of animals past the optimal age of selection results in an escalation of production costs and a delay in the receipt of income from the sale of any superior animals (MacLeod, 1991). In all instances, the optimal age of selection is a necessary compromise between the cost of production and the accuracy of selection.

A guide to the optimal age of selection for each character is provided by an assessment of the relationship between the relative rankings of the animals at each age of measurement and the relative rankings at the following measurement age or in later adult life. The utilisation of phenotypic correlations between these stages are used to provide the assessment.
5.2.4. Number of Records Required to Provide Accuracy of Selection:

An interpretation of the number of records required to provide accuracy of selection was based on the calculation of the accuracy of producing ability for each character.

It can be expected that as the age at which performance measurements are collected decreases, the potential accuracy of the selection decision also decreases because of the influence of early-life non-genetic maternal and other environmental factors. While it is possible to increase the accuracy of measurements made at early ages by including corrections for these differences, on most sheep breeding properties it is not feasible to collect the relevant records on a routine basis (Brien, 1994; Rogan et al., 1995). The most practical methods of increasing the accuracy of selection are to delay the collection of performance measurements until a later age, or to utilise a greater number of records.

A guide to the number of records required to obtain an acceptable level of selection accuracy can be obtained from an assessment of the accuracy of producing ability (see Table: 4.5.1. and Table: 4.5.2.).

While a selection accuracy that approaches 100 per cent would be most desirable, this would be impossible to achieve, even if four successive records were collected on each animal. As the number of records that need to be collected increase, the age of the animals also increases, extending the time necessary to obtain a final assessment of the animals.
In addition, the collection and assessment of some records (eg. fibre diameter) may involve considerable expense. A minimisation in the number of records that need to be collected will reduce the age of the animals when selection can occur, as well as minimising the cost of record collection. As a compromise between selection accuracy and the need to minimise the number of records collected, a selection accuracy level of at least 75 per cent is desirable.

5.3 Mean Fibre Diameter:
A 50 per cent reduction in yearly rainfall between 1992 and 1993 when the 18 month and 30 month measurements were collected, had a marked influence on mean fibre diameter (reduced from 22.3 microns to 21.2 microns). In 1994 when the 42 month measurement was collected, the rainfall reduced by 35 per cent on the previous year. Despite this further decline in rainfall and corresponding paddock feed availability, the mean fibre diameter increased from 21.2 microns to 23.6 microns

Although the relationship between mature-age performance and seasonal conditions may initially have appeared to be giving a mixed message, an analysis of the coefficient of variation for fleece and body characters provided some explanation (see Figure: 4.1.1.). Measures of mean fibre diameter reflected the cumulative effects of the growing conditions during the entire period preceding measurement. The coefficient of variation for mean fibre diameter was very similar at each age of measurement.
At each age of measurement, the coefficient of variation was also far lower than is displayed by any other measured character. It could be clearly identified that while the mean fibre diameter measurement was affected by animal age and seasonal conditions, the coefficient of variation remained largely unaffected.

An estimated repeatability of 0.67 for mean fibre diameter was calculated by the Wanbi trial. This estimate was the same as Mullaney et al. (1970), and very similar to the one reported by Wade et al. (1992). In relation to the range of estimates cited in other projects reviewed, this estimate falls in the mid range.

In a review of previous work, Turner (1970) reported a range of repeatability estimates from 0.50 to 0.80. At the low end of the estimates for fibre diameter, Young et al. (1960) reported a range of 0.50-0.54, while Beattie reported an estimate of 0.53. A higher estimate of 0.83 was reported by Heaton-Harris et al. (1969) and 0.76 by Atkins et al. (1992).

The repeatability estimate for mean fibre diameter reported by this trial at Wanbi was 0.67 and selection for decreased fibre diameter would result in a reasonable level of improvement within the current flock.

The phenotypic correlation of mean fibre diameter at the 6 month Vs 12 month comparison was 0.66 and experienced a highly significant increase (P<0.01) to 0.73 at the 12 month Vs 18 month comparison.
After this stage, there was no significant difference in the phenotypic correlation. When the phenotypic correlation of 6 month Vs adult (0.58) was compared with 12 month Vs adult (0.77), the difference was of lower significance (P<0.05). A comparison with the next measurement stage showed there was no significant difference. Other researchers have reported phenotypic correlation coefficients for 9-12 month measurements in the range 0.60-0.77, while the range for 13-18 month measurements is in the range 0.77-0.80 (Young et al., 1960; Ponzoni et al., 1995a; Rogan et al., 1995; Brash et al., 1997; Hynd et al., 1997). This indicated that measurements of mean fibre diameter after 12 months would not significantly improve the selection of sheep. Other workers have also demonstrated that in sheep selection programs, early selection for mean fibre diameter could be considered to be as efficient as later selection (Atkins, 1987; Mortimer, 1987; Atkins et al. 1990).

Based on the previously established 75 per cent benchmark level for accuracy of producing ability, a single record of mean fibre diameter provided a sufficient level of accuracy (0.82) to enable selection to occur with confidence. As mean fibre diameter is relatively expensive to measure, a two-stage selection program conducted during times when the price premium for micron is low may delay the assessment of this character until the second-stage when a fewer number of animals will need to be tested.
**KEY OUTCOMES - MEAN FIBRE DIAMETER**

- Estimated repeatability of mean fibre diameter was high (0.67).
- Rankings of animals were influenced by environmental variations between seasons.
- A single record of mean fibre diameter taken at 12 months of age provided an accurate indication of adult performance.

5.4 Greasy Fleece Weight:

Over the four year period of the field trial (1991 to 1994), the coefficient of variation for greasy fleece weight exhibited quite a marked variation. At the 6 month measurement it was in excess of 26 per cent, reducing markedly to around 10 per cent at the 18 month, 30 month and 42 month measurement stages.

Greasy fleece weights recorded in the harsh semi-arid farming environment at Wanbi Agricultural Centre were predominantly a factor of wool growth and the innate contamination of the fleeces with soil and vegetable matter. During the project, the influence that the soil and sand content of the fleece had on greasy fleece weight was considerable. This was largely independent of genetic merit of the animals and the prevailing seasonal conditions, but markedly influenced by the amount of wool growth at the time of shearing (6 months at the first three shearings and 12 months at the second shearing).
Due to innate fleece characteristics of individual sheep, dust penetration and sand content affected each animal within the flock to a varying extent. Consequently, differences in greasy fleece weight between seasons and between individual sheep could be expected to vary considerably.

This trial calculated a repeatability of 0.55 for greasy fleece weight. While this figure was higher than the range of 0.40-0.50 reported by Ford (1961), it was below the range of 0.60-0.80 reported by a number of other researchers (see Table: 2.4.1.1.). In the harsh semi-arid Wanbi environment, sand and vegetable matter content of the fleece were a major consideration and varied markedly between years. This unpredictable environmental factor contributed markedly to the low repeatability estimate of greasy fleece weight relative to previously established estimates.

Ponzoni (1979a) reported an estimated repeatability of 0.61 for greasy fleece weight in South Australian strong wool Merino sheep. This was also at the lower end of the range reported by other researchers. Based on the repeatability estimate reported by this trial and supported by the estimate of Ponzoni (1979a), it can be concluded that the repeatability estimate for greasy fleece weight in South Australian strong wool Merino sheep being run in a semi-arid cereal/sheep farming environment is lower than for other types of Merino sheep.
For measurements of greasy fleece weight, there was a very highly significant (P<0.001) difference in the phenotypic correlation coefficient between the 6 month Vs 12 month comparison (0.56) and the 12 month Vs 18 month comparison (0.72). However at the next comparison stage of 18 months Vs 30 months, there was no significant difference in phenotypic correlation, indicating that selection at the earlier stage was just as efficient as selection based on the later stage measurements.

Although the phenotypic correlation of the 6 month measurement Vs adult performance of greasy fleece weight rankings was very low (0.30), there was a very highly significant increase in phenotypic correlation (P<0.001) at the 12 month measurement age (0.63). A number of other researchers agree with these correlations. Young et al. (1965) also reported low phenotypic correlations at 5.5-6.5 months of age (0.43), while Ponzoni (1979a) reported that the phenotypic correlation could be as low as 0.40 for animals measured at 4-6 months of age. At the 9-12 month measurement stage, a phenotypic correlation range of 0.52-0.55 has been established (Rogan et al, 1995; Ponzoni et al., 1995a; Brash et al., 1997). Atkins et al. (1990) reported that 10 per cent of the variance in fleece weight at this stage is still due to maternal and early environmental effects.
A further very highly significant increase in phenotypic correlation of greasy fleece weight (P<0.001) occurred when measurements recorded at an age of 18 months were compared with adult performance (0.81).

As reported by Atkins and Mortimer (1987), this indicated that hogget and adult greasy fleece weight may need to be considered as two separate traits. Using South Australian bloodline strong wool Merino sheep, Ponzoni (1979a) also established that the phenotypic correlation for greasy fleece weight at this age can be as high as 0.80. The phenotypic correlations established by the trial at Wanbi indicate that the accuracy of selection for greasy fleece weight could be significantly improved by measuring animals at 18 months of age.

An interpretation of the accuracy of producing ability indicated that two records of greasy fleece weight were required to be collected in order to attain the 75 per cent level of accuracy. The degree of accuracy involved in the selection process was intimately linked to the repeatability and phenotypic correlation of each measured character. An accurate assessment of greasy fleece weight would require the use of a two-stage selection program. Greasy fleece weight would need to be measured at each stage and the final selection decision would be based on animal rankings derived from the combined measurements collected at both stages.
KEY OUTCOMES - GREASY FLEECE WEIGHT

- Estimated repeatability of greasy fleece weight was 0.55.
- The strong-wool South Australian Merino had an estimated repeatability for greasy fleece weight in the lower range of previously established estimates.
- To enable accurate selection for greasy fleece weight, sheep must undergo a two-stage selection program with measurements being collected at 12 months and 18 months of age.

5.5 Clean Fleece Weight:

Measures of clean fleece weight did reflect the cumulative effects of the growing conditions during the entire period preceding measurement. Although the coefficient of variation for clean fleece weight was relatively large (22%) at the 6 month measurement, it then reduced at each subsequent age of measurement. The mean measurement for clean fleece weight was influenced by the combined effects of animal age and growth phase, period between shearing (6 months or 12 months) flock genetic make-up, long term environmental factors and medium term seasonal factors. Despite the between-season response of clean fleece weight to these various factors, the coefficient of variation within the measurement group was not markedly influenced at ages beyond 6 months. The coefficient of variation for clean fleece weight was largely unaffected by seasonal conditions experienced by the flock.
The repeatability estimate calculated by this research project for clean fleece weight was 0.33, which was below the value reported by other workers. Despite this, the repeatability estimate was very highly significant (P<0.001). The closest estimate to the one being reported was 0.59-0.68, cited by Young et al. (1960) who worked with medium-wool Peppin Merino sheep. While working with a similar type of South Australian strong wool Merino sheep as the ones used in the Wanbi trial, Ponzoni (1986) reported a far higher estimated repeatability for clean fleece weight of 0.80.

Although the repeatability estimate for clean fleece weight reported by the Wanbi trial was relatively low, its relativity with the repeatability estimate for greasy fleece weight followed the same trend as many other research projects.

The Wanbi trial reported a higher repeatability estimate for greasy fleece weight (0.55) than for clean fleece weight (0.33). The comparative results of other researchers who also observed that the repeatability estimate for GFW was higher than for CFW are listed in Table 5.5.1.

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>GREASY FLEECE WT.</th>
<th>CLEAN FLEECE WT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young et al. (1960)</td>
<td>0.64 - 0.66</td>
<td>0.59 - 0.68</td>
</tr>
<tr>
<td>Beattie (1961)</td>
<td>0.68</td>
<td>0.65</td>
</tr>
<tr>
<td>Heaton-Harris et al. (1969)</td>
<td>0.78</td>
<td>0.71</td>
</tr>
<tr>
<td>Mullaney et al. (1970)</td>
<td>0.79</td>
<td>0.78</td>
</tr>
<tr>
<td>Atkins et al. (1992)</td>
<td>0.66</td>
<td>0.62</td>
</tr>
<tr>
<td>Manson (1997)</td>
<td>0.55</td>
<td>0.33</td>
</tr>
</tbody>
</table>
In particular, the repeatability estimates published by Atkins et al. (1992) were representative of a very wide range of Merino bloodline types. The relativity highlighted in Table: 5.5.1. suggested that productivity increases within flocks of Merino sheep would be greater if the program concentrated on measuring greasy fleece weight rather than clean fleece weight, particularly in flocks of South Australian strong wool Merinos. However this would also be highly dependant on the relative economic values of greasy fleece weight and clean fleece weight.

The phenotypic correlation of clean fleece weight measurements collected at 6 months Vs 12 months was very low (0.32). However the phenotypic correlation between adjacent ages was not significantly altered at the 12 month Vs 18 month comparison (0.39) or the 18 month Vs 30 month comparison (0.41). Despite this, when the phenotypic correlation of clean fleece weight measurement rankings at 6 months Vs adult performance (0.17) were compared with the phenotypic correlation of 12 months Vs adult (0.39), the difference was very highly significant (P<0.001). A further very highly significant difference (P<0.001) occurred when a comparison was made with the 18 month Vs adult phenotypic correlation (0.55).

The phenotypic correlation for 12 months Vs adult (0.39) was very similar to the lower end of the range (0.40) reported by Hynd et al. (1997), also using strong wool South Australian Merino sheep. However, it was in contrast to the range of phenotypic correlation estimates of 0.70-0.90 reported by Atkins (1987).
The 18 month Vs adult phenotypic correlation of 0.55 was very similar to a phenotypic correlation of 0.60 reported by Hynd et al. (1997).

Phenotypic correlations of clean fleece weight produced by this trial indicated that while the phenotypic correlation between early age measurements and adult performance were low, significant improvement could be made by undertaking measurements at later ages. In this case, a moderate level of phenotypic correlation was not achieved until measurements were made at 18 months of age.

As shown in Table 4.5.1., three records of clean fleece weight were required to be collected in order to attain the 75 per cent level of accuracy. The degree of accuracy involved in the selection process was intimately linked to the repeatability and phenotypic correlation of each measured character. The use of more than one record for fleece weight to increase the accuracy of selection has also been reported by Atkins (1987).

As the trial at Wanbi indicated that three records were required to achieve the required level of selection accuracy for clean fleece weight, a multi-stage selection process is necessary. However the realities of practical sheep selection mean that the collection of three records to provide a sufficiently accurate assessment of clean fleece weight is not feasible. Because of this, a two-stage assessment of the animals will need to be conducted.
Where an assessment of clean fleece weight is required in isolation of other characters, the required level of accuracy will not be achieved.

KEY OUTCOMES - CLEAN FLEECE WEIGHT

- *Estimated repeatability of clean fleece weight was relatively low (0.33).*
- *The strong-wool South Australian Merino had an estimated repeatability for clean fleece weight in the lower range of previously established estimates.*
- *To enable practical selection for clean fleece weight, sheep must undergo a two-stage selection program with measurements being collected at 12 months and 18 months of age. This program will not provide a desirable level of accuracy if selection for clean fleece weight is carried out in isolation of other characters.*

5.6 Body Weight:

Despite a 50 per cent reduction in yearly rainfall between 1992 and 1993 when the 18 month and 30 month measurements were collected, the mean measurements for body weight increased from 51 kg to 57 kg. In 1994 when the 42 month measurement was collected, although the rainfall reduced by a further 35 per cent and paddock feed availability declined, body weight again increased from 57 kg to 68 kg. By its nature, measurements of body weight often reflected the effects of short-term environmental influences such as nutritional status as well as the normal growth pattern of young animals.
Therefore the mean measurements of body weight did not necessarily reflect long-
term influence of yearly rainfall and seasonal paddock feed conditions. Despite this,
the coefficient of variation for body weight reduced with advancing age, highlighting
that although the between-season variation may have been largely governed by
short term fluctuations in nutritional status, the influence of between-animal
differences actually reduced.

The repeatability estimate of 0.68 for body weight was in the mid-range of estimates
obtained by other researchers (see Table: 2.4.1.7.). Estimates previously reported
ranged from 0.50 to 0.84. The repeatability estimate for body weight obtained by this
trial was very similar to that cited by two previously published reports that
investigated a representative range of Merino bloodlines. Without doubt, the
estimate that was most representative of a wide range of Merino types and
backgrounds was that reported by Atkins et al. (1992). Their repeatability estimate
of 0.67 was obtained using an extremely wide range of 133 separate Merino
bloodlines entered in NSW wether trials. Turner (1977) also reported on a range of
trials representing a wide range of Merino types. Her averaged repeatability
estimate for body weight was 0.70. The repeatability estimate calculated by this trial
for body weight was 0.68.

For body weight, the similar high level of the phenotypic correlation (0.73) of both
the 6 Vs 12 month comparison and the 12 Vs 18 month comparison indicated that
selection for this character would be efficient at the earlier ages (see Table: 4.2.1.).
There was no significant difference between measurements at these two stages. When an analysis of the comparison of measurement age and adult performance (see Table: 4.3.1.) was undertaken, it could be seen that there was a very highly significant increase in the phenotypic correlation coefficient \((P<0.001)\) between the 6 month measurement (0.56) and the 12 month measurement (0.76). The lower significance of the increase in phenotypic correlation between the 12 month and 18 month assessment ages \((P<0.01)\) indicated that there was little to be gained by delaying selection based on body weight until 18 months. Also, the accuracy of producing ability based on one measurement was high \((0.83)\) for body weight.

This trend agreed with the reports of other researchers. Young et al. (1965) reported a low phenotypic correlation of 0.35 for rankings of body weight at 5.5-6.5 months compared with measurement rankings at a later age. However the phenotypic correlation between the next measurement age of 9-12 months and later life determined by a number of researchers was in the high range of 0.72-0.87 (Rogan et al., 1995; Ponzoni et al., 1995a; Brash et al., 1997). When measurements of body weight were performed at the next stage of 13-18 months, Young et al. (1960) reported a phenotypic correlation of 0.81, which was no better than the earlier-age body weight measurements reported by others.

The phenotypic correlations between adjacent ages indicated selection for body weight would be efficient at earlier ages.
However as the phenotypic correlations of age of measurement Vs adult performance increased significantly between the 6 month and the 12 month measurements, the 12 month age is the earliest at which the measurement should be taken. The high accuracy of producing ability using one record (0.83) indicated that a single measurement of body weight recorded at 12 months of age would provide an accurate indication of adult performance.

As body weight is easy and inexpensive to measure on a large number of animals, if an overall multi-character selection program for a flock demanded a two-stage selection process, body weight would be included in the first stage. This would enable early culling of inferior animals (Ponzoni, 1987).

**KEY OUTCOMES - BODY WEIGHT**

- *Estimated repeatability of body weight was high (0.68).*
- *The strong-wool South Australian Merino had an estimated repeatability for body weight in the mid range of previously established estimates.*
- *Accurate selection for body weight could be undertaken through the use of a single measurement collected at 12 months of age.*

**5.7 Woolplan Indices:**

The coefficient of variation for the various Woolplan indices options provided an indication of the effect of age and seasonal conditions.
All of the Woolplan CFW and GFW indices maintained relatively constant coefficient of variation coefficients across the range of ages. While the GFW & CFW index options #1, #3 and #4 (see Figure: 4.1.2. and Figure: 4.1.3.) tended to group together in the same range, the Woolplan index option #2 consistently maintained a lower coefficient of variation at each measurement age. The coefficient of variation of this Woolplan option was also less affected by animal age and environmental variation than any of the other Woolplan options.

Differences between the indices reflected the relative importance of the traits comprising those indices (eg. Woolplan index #2 mainly reflected fleece weight).

Apart from the CFW options for Woolplan indices #1 and #2, estimated repeatabilities for all Woolplan indices were in the range 0.61-0.69. This was slightly lower than the repeatability estimate of 0.74 reported by Wade et al. (1992). Lower repeatability estimates for the CFW options of Woolplan indices #1 and #2 were because of the large emphasis they placed on clean fleece weight relative to fibre diameter and also the influence of the low repeatability estimate of CFW in the Wanbi trial. The repeatability estimates of the Woolplan indices were very similar to the repeatability estimates of the individual traits. This was also in accord with observations reported by Wade et al. (1992).

Woolplan option #1 was structured so that there was only a slight emphasis on reducing fibre diameter, with a low assumed micron premium of 5 per cent.
Woolplan option #2 resulted in no change in the fibre diameter of the flock, with a very low assumed micron premium of 1-2 per cent. Because of the reduced weighting placed on fibre diameter by both of these Woolplan options, the weighting placed on fleece weight increased. As clean fleece weight had a relatively low repeatability estimate in this trial, the influence of clean fleece weight served to reduce the repeatability estimate of all the CFW Woolplan index options, and in particular the CFW options for indices #1 and #2.

The high repeatability estimates derived for the CFW and GFW options for Woolplan indices #3 & #4 reflected the larger emphasis on mean fibre diameter which was more highly repeatable. Selection using these indices and the GFW options for Woolplan indices #1 & #2 result in improvement within the flock.

The phenotypic correlations of all the Woolplan GFW indices and all Woolplan CFW indices apart from #1 and #2 at the 6 months Vs 12 months comparison were high, and were very highly significantly different (P<0.001) from the adjacent older age measurement comparison of 12 months Vs 18 months (see Table: 4.2.2.). As none of the phenotypic correlations for the 12 month Vs 18 month comparisons were significantly different from the 18 month Vs 30 month comparisons, it could be concluded that the utilisation of measurements beyond the 12 month age would not result in an improvement in the calculation of any of the Woolplan indices.
The emphasis placed on the reduction in the fibre diameter of the flock increases from Woolplan option #2 to #1 to #3 and to #4. Correspondingly, the assumed micron premium used in the calculation of the Woolplan indices increases across these options and the implied weighting for fleece weight (CFW & GFW) decreases. The low phenotypic correlation of CFW calculated in this trial had a flow-on influence in the Woolplan indices that have an innate higher weighting for CFW (#1 & #2), by producing lowered phenotypic correlations in these particular indices.

The effect of this relationship can be seen in the relativity of the phenotypic correlations for the first measurement stage (6 month Vs adult performance). The phenotypic correlations increased as the weighting for fibre diameter increased (see Table: 4.3.2.). There was a very highly significant difference (P<0.001) between the correlations at this first stage of measurement (6 months Vs adult) and those at the next stage (12 months Vs adult). However the difference in the phenotypic correlation between this stage (12 months Vs adult) and the next (18 month Vs adult) was not significant for the two index options that placed the least weighting on CFW. These were the GFW indices options #3 and #4. For the other CFW and GFW options, the difference was very highly significant (P<0.001).
It can be concluded that because of the variation in weighting for fleece weight in the four Woolplan indices options and the confounding effect of the low phenotypic correlation for CFW, no benefit will be gained from the inclusion of measurements collected at ages greater than 12 months for the GFW options in Woolplan indices #3 and #4. However, although gains may be made from the inclusion of measurements from older animals in the other Woolplan indices, taking into account the analysis of the phenotypic correlations for adjacent measurement ages, it is concluded that the most appropriate age to collect performance measurements for all Woolplan indices is 12 months. This is in agreement with Wade et al. (1992) who reported that in relation to Woolplan indices, 13 month measurements are a reliable indication of later performance.

All GFW Woolplan options and the CFW Woolplan options for indices #3 and #4 provide a satisfactory level of selection accuracy with the use of measurements obtained from a single-record. This is because the low weighting placed on fleece weight relative to fibre diameter in each of these selection indices reduces the effect of the inaccuracy of the single fleece weight record. If producers choose to use the CFW option for Woolplan indices #1 and #2, two records will still be required in order to provide the required degree of selection accuracy.
KEY OUTCOMES - WOOLPLAN

- Estimated repeatability of all Woolplan indices apart from CFW #1 and #2, was high (range of 0.61 - 0.69). Estimated repeatability of CFW #1 and #2 were 0.54 and 0.43 respectively.

- The strong-wool South Australian Merino had an estimated repeatability for Woolplan indices below that of a previously established estimate.

- Repeatability estimates and phenotypic correlations for all Woolplan indices were similar to those for the individual traits. They decreased as the weighting for clean fleece weight increased in relation to the weighting for fibre diameter.

- Accurate selection using all Woolplan indices (apart from CFW #1 and #2) could be undertaken through the use of single measurements collected at 12 months of age.

5.8 Conclusions - Recommended Strategy for the Selection of Merino Sheep:

Provided that non-genetic between-animal variation is minimised and the procedures associated with data collection are sound, sheep producers can have a high degree of confidence in the reliability of objective performance measurements collected within their flocks. This recommendation is supported by studies conducted by Heaton-Harris et al. (1969), Black and Reis (1979) and Eady et al. (1987).
The trial at Wanbi provided an indication that when compared with other Merino strains present in Australia, the estimates of repeatability and the phenotypic correlations between early ages of measurement and adult performance for the South Australian strong wool Merino strain are in the low to medium range. In relation to greasy fleece weight, this is supported by work involving South Australian strong wool sheep reported by Ponzoni (1979). Also working with this bloodline of sheep, Hynd et al. (1997) reported phenotypic correlations in the low to mid range between early age measurements and later age performance for both clean fleece weight and mean fibre diameter. This supports the findings of the trial at Wanbi.

Assessment of phenotypic correlations and accuracy of selection indicate quite strongly that for all characters, measurements collected at the 6 month animal age do not provide a satisfactory indication of relative performance superiority of the animals during later adult life. However, single measurements collected at the 12 month age do provide a reliable and accurate indication of later performance for body weight, mean fibre diameter and all Woolplan selection index options (apart from the CFW options for indices #1 and #2). Delaying measurement and selection for these characters until a later age will not improve the long term productivity of the flock.
Although assessment of greasy fleece weight at 12 months of age does provide a reliable indication of adult performance, a second measurement of greasy fleece weight collected at 18 months will further improve the ability to predict relative merit of the animals at later age as well as the level of accuracy. A reliable assessment of clean fleece weight cannot be made until at least three records are collected. However in a practical flock management system, if selection for clean fleece weight is desired, measurements must be undertaken at 12 months and 18 months of age in a two-stage process. The mean value of the measurements undertaken at 12 months and 18 months of age can be used to predict animal performance at later ages.

Based on these findings, there are two alternative sheep selection programs available to producers. The first is a two-stage selection procedure. To minimise the cost of the selection process, the assessment of any characters that are expensive to measure and require only one record, are delayed until the second-stage of the process. Assessment of any characters that are inexpensive to measure and require only one record, should be conducted at the first-stage to enable early culling of inferior animals (Ponzoni, 1987). Characters that require two records would need to be measured on both occasions.

The two-stage selection process resulting from the Wanbi trial involves initial measurement of the flock for greasy fleece weight and body weight at 12 months of age.
Following a culling program based on the body weight rankings, the remaining animals are assessed on a second occasion at 18 months of age, using measurements of greasy fleece weight (final assessment based on the mean of the 12 month and 18 month GFW measurements) and mean fibre diameter. Clean fleece weight measurements are not utilised in this two-stage process.

This is very similar to the two-stage selection method reported by Butt and Kearins (1987) where whole drops of rams are tested at around 9-12 months of age, with an elite group of rams being re-tested at a later age. Atkins et al. (1990) reported that a two-stage selection program conducted at this age would provide substantial benefits in excess of 25 per cent over single stage selection conducted at the same age.

A major problem with the two-stage selection process formulated as a result of the Wanbi trial is the omission of clean fleece weight measurements. If clean fleece weight were to be included in the selection process, as it is a relatively expensive measurement to analyse, the requirement for measurements to occur at both the 12 month and 18 month ages would substantially increase the cost of flock selection. Even if the flock was subjected to a two-stage selection process, a satisfactory level of selection accuracy for clean fleece weight would not be provided.
The favoured alternative to the two-stage selection procedure is the use of a selection index that includes performance measurements collected at the single measurement age of 12 months. Using the Woolplan selection index, GFW options for selection indices #1, #2, #3 and #4, or CFW options for indices #3 and #4 would all provide a highly reliable indication of adult animal performance.

Utilisation of the selection index would provide the sheep producer with the ability to obtain a more comprehensive gauge of the overall merit of each animal. It provides a higher quality information source that allows for the relative contribution that each measured character makes to the overall economic merit of the individual sheep. Use of one of the recommended indices to carry out the selection process also allows the assessment of the flock to be completed at the 12 month stage, using only one set of measurements. This then permits early selection of superior individuals and culling of inferior animals, while reducing the cost of measuring the animals.
KEY OUTCOMES - SHEEP SELECTION POLICY

- Repeatability estimates for the strong-wool South Australian Merino strain are in the low to medium range of previously established estimates for Australian Merino strains.

- Between-season environmental variation does not markedly affect relative animal rankings for measured characters.

- Measurements collected on animals at 6 months of age do not provide a satisfactory indication of relative performance superiority of the animals during later adult life.

- When animal selection is based on individual characters without the use of a selection index, a two-stage process involving measurements collected at 12 months and 18 months of age is necessary. Measurements collected at 12 months are body weight and greasy fleece weight, while measurements collected at 18 months are greasy fleece weight and mean fibre diameter.

- The preferred option is a single-stage selection program involving the inclusion of performance measurements collected at 12 months of age into a selection index. Woolplan selection indices suitable for this are all GFW options and the CFW options for #3 and #4.
6. APPENDICES

6.1 APPENDIX: 1.

REPEATABILITY ESTIMATES AND PHENOTYPIC CORRELATIONS OF WOOL & BODY CHARACTERS
Table: 6.1.1.
REPEATABILITY ESTIMATES FOR GREASY FLEECE WEIGHT IN SOUTH AUSTRALIAN STRONG WOOL MERINO FLOCKS
(Ponzoni 1979a)

<table>
<thead>
<tr>
<th>FLOCK</th>
<th>1st AGE</th>
<th>2nd AGE</th>
<th>REPEATABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11 months</td>
<td>19 months</td>
<td>0.54</td>
</tr>
<tr>
<td>2</td>
<td>8 months</td>
<td>15 months</td>
<td>0.62</td>
</tr>
<tr>
<td>3</td>
<td>8 months</td>
<td>20 months</td>
<td>0.62</td>
</tr>
<tr>
<td>4</td>
<td>8 months</td>
<td>15 months</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Table: 6.1.2.
REPEATABILITY ESTIMATES FOR UNSELECTED MEDIUM PEPPIN MERINO RAMS AND EWES
(Young et al. 1960)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>REPEATABILITY</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EWES</td>
<td>RAMS</td>
<td>-------</td>
</tr>
<tr>
<td>Greasy fleece weight</td>
<td>0.64</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>Yield</td>
<td>0.54</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>Clean fleece weight</td>
<td>0.59</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td>Body Weight</td>
<td>0.67</td>
<td>0.73</td>
<td></td>
</tr>
<tr>
<td>Wrinkle Score</td>
<td>0.48</td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td>Face Cover</td>
<td>0.49</td>
<td>0.36</td>
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</tr>
<tr>
<td>Fibre density</td>
<td>0.46</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Fibre diameter</td>
<td>0.50</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>Staple length</td>
<td>0.58</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>Crimps per inch</td>
<td>0.61</td>
<td>0.55</td>
<td></td>
</tr>
</tbody>
</table>
Table: 6.1.3.
ESTIMATED REPEATABILITY OF FLEECE AND BODY CHARACTERS
OF MEDIUM PEPPIN EWES
(Beattie 1961)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>REPEATABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greasy wool weight</td>
<td>0.68 (± 04)</td>
</tr>
<tr>
<td>Per cent. clean scoured yield</td>
<td>0.65 (± 04)</td>
</tr>
<tr>
<td>Clean wool weight</td>
<td>0.65 (± 02)</td>
</tr>
<tr>
<td>Fibre diameter</td>
<td>0.53 (± 05)</td>
</tr>
<tr>
<td>C.V. of fibre diameter</td>
<td>0.45 (± 06)</td>
</tr>
<tr>
<td>Staple length</td>
<td>0.57 (± 05)</td>
</tr>
<tr>
<td>Crimps per inch</td>
<td>0.71 (± 04)</td>
</tr>
<tr>
<td>Body weight</td>
<td>0.80 (± 03)</td>
</tr>
<tr>
<td>Neck score</td>
<td>0.62 (± 16)</td>
</tr>
<tr>
<td>Side score</td>
<td>0.50 (± 07)</td>
</tr>
</tbody>
</table>

Table: 6.1.4.
REPEATABILITY ESTIMATES FOR MERINO EWES
(Mullaney et al. 1970)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>REPEATABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greasy fleece weight</td>
<td>0.79</td>
</tr>
<tr>
<td>Yield</td>
<td>0.78</td>
</tr>
<tr>
<td>Clean fleece weight</td>
<td>0.78</td>
</tr>
<tr>
<td>Mean fibre diameter</td>
<td>0.68</td>
</tr>
<tr>
<td>Staple length</td>
<td>0.57</td>
</tr>
<tr>
<td>Crimps per inch</td>
<td>0.41</td>
</tr>
<tr>
<td>Colour</td>
<td>0.47</td>
</tr>
<tr>
<td>Handle</td>
<td>0.38</td>
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<tr>
<td>Character</td>
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<tr>
<td>Quality number</td>
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Table: 6.1.5.
POOLED REPEATABILITY ESTIMATES
FOR FINE AND MEDIUM PEPPIN MERINO SHEEP
(Turner 1977)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>REPEATABILITY RANGE</th>
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<tbody>
<tr>
<td>Greasy wool weight</td>
<td>0.6-0.8</td>
</tr>
<tr>
<td>Percentage clean yield</td>
<td>0.5-0.8</td>
</tr>
<tr>
<td>Clean wool weight</td>
<td>0.6-0.8</td>
</tr>
<tr>
<td>Average fibre diameter</td>
<td>0.5-0.8</td>
</tr>
<tr>
<td>Staple length</td>
<td>0.5-0.7</td>
</tr>
<tr>
<td>No. of crimps per inch</td>
<td>0.3-0.6</td>
</tr>
<tr>
<td>Body weight</td>
<td>0.7</td>
</tr>
<tr>
<td>Wrinkle score</td>
<td>0.5-0.7</td>
</tr>
<tr>
<td>Face cover score</td>
<td>0.4-0.5</td>
</tr>
</tbody>
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Table: 6.1.6.
REPEATABILITY ESTIMATES FOR FLEECE CHARACTERS
AND WOOLPLAN INDICES IN FINE WOOL MERINO RAMS
(Wade et al. 1992)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>REPEATABILITY</th>
<th>CONFIDENCE LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greasy fleece weight</td>
<td>0.66</td>
<td>0.57 - 0.73</td>
</tr>
<tr>
<td>Body weight</td>
<td>0.73</td>
<td>0.66 - 0.79</td>
</tr>
<tr>
<td>Fibre diameter</td>
<td>0.67</td>
<td>0.59 - 0.74</td>
</tr>
<tr>
<td>Yield</td>
<td>0.77</td>
<td>0.71 - 0.82</td>
</tr>
<tr>
<td>Clean fleece weight</td>
<td>0.75</td>
<td>0.69 - 0.80</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.66</td>
<td>0.58 - 0.73</td>
</tr>
<tr>
<td>Index #1</td>
<td>0.74</td>
<td>0.67 - 0.79</td>
</tr>
<tr>
<td>Index #2</td>
<td>0.74</td>
<td>0.67 - 0.79</td>
</tr>
<tr>
<td>Index #3</td>
<td>0.73</td>
<td>0.66 - 0.79</td>
</tr>
<tr>
<td>Index #4</td>
<td>0.73</td>
<td>0.66 - 0.79</td>
</tr>
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Table: 6.1.7.
PHENOTYPIC CORRELATIONS FOR MEDIUM PEPPIN MERINO SHEEP
5.5/6.5 MONTHS Vs 15/16 MONTHS
(Young et al. 1965)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>PHENOTYPIC CORRELATION</th>
<th>95% LIMITS</th>
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<tbody>
<tr>
<td>Body weight</td>
<td>0.35</td>
<td>0.31-0.39</td>
</tr>
<tr>
<td>Greasy fleece weight</td>
<td>0.43</td>
<td>0.37-0.49</td>
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Table: 6.1.8.
PHENOTYPIC CORRELATION BETWEEN RECORDS AT A SINGLE AGE
AND LIFETIME PERFORMANCE IN MEDIUM PEPPIN EWES
(Young et al. 1960)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>AGE</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>15/16 m.</td>
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<tr>
<td>Greasy fleece weight</td>
<td>0.72</td>
</tr>
<tr>
<td>Yield</td>
<td>0.82</td>
</tr>
<tr>
<td>Clean fleece weight</td>
<td>0.72</td>
</tr>
<tr>
<td>Body Weight</td>
<td>0.81</td>
</tr>
<tr>
<td>Wrinkle score</td>
<td>0.75</td>
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<tr>
<td>Face cover score</td>
<td>0.85</td>
</tr>
<tr>
<td>Fibre density</td>
<td>0.78</td>
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<tr>
<td>Fibre diameter</td>
<td>0.77</td>
</tr>
<tr>
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<tr>
<td>Crimps per inch</td>
<td>0.85</td>
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Table: 6.1.9.
PHENOTYPIC CORRELATION IN MEDIUM PEPPIN EWES
15/16 MONTHS Vs LATER AGES
(Young et al. 1960)

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<thead>
<tr>
<th>CHARACTER</th>
<th>LATER AGE</th>
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<tbody>
<tr>
<td></td>
<td>30 m.</td>
</tr>
<tr>
<td>Greasy fleece weight</td>
<td>0.68</td>
</tr>
<tr>
<td>Yield</td>
<td>0.54</td>
</tr>
<tr>
<td>Clean fleece weight</td>
<td>0.58</td>
</tr>
<tr>
<td>Body Weight</td>
<td>0.66</td>
</tr>
<tr>
<td>Wrinkle score</td>
<td>0.48</td>
</tr>
<tr>
<td>Face cover score</td>
<td>0.52</td>
</tr>
<tr>
<td>Fibre density</td>
<td>0.46</td>
</tr>
<tr>
<td>Fibre diameter</td>
<td>0.43</td>
</tr>
<tr>
<td>Staple length</td>
<td>0.58</td>
</tr>
<tr>
<td>Crimps per inch</td>
<td>0.66</td>
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Table: 6.1.10.
PHENOTYPIC CORRELATIONS BETWEEN CONSECUTIVE AGES IN MEDIUM PEPPIN MERINO RAMS
(Young et al. 1960)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>10/12 v 15/16 months</th>
<th>15/16 v 30 months</th>
<th>15/16 v 42 months</th>
<th>30 v 42 months</th>
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<tbody>
<tr>
<td>Greasy fleece weight</td>
<td>0.62</td>
<td>0.71</td>
<td>0.67</td>
<td>0.80</td>
</tr>
<tr>
<td>Yield</td>
<td>0.65</td>
<td>0.69</td>
<td>0.58</td>
<td>0.80</td>
</tr>
<tr>
<td>Clean fleece weight</td>
<td>0.60</td>
<td>0.76</td>
<td>0.67</td>
<td>0.77</td>
</tr>
<tr>
<td>Body Weight</td>
<td>0.85</td>
<td>0.79</td>
<td>0.72</td>
<td>0.80</td>
</tr>
<tr>
<td>Wrinkle score</td>
<td>0.56</td>
<td>0.59</td>
<td>0.60</td>
<td>0.77</td>
</tr>
<tr>
<td>Face cover score</td>
<td>0.55</td>
<td>0.46</td>
<td>0.28</td>
<td>0.17</td>
</tr>
<tr>
<td>Fibre density</td>
<td>0.50</td>
<td>0.48</td>
<td>0.35</td>
<td>0.54</td>
</tr>
<tr>
<td>Fibre diameter</td>
<td>0.65</td>
<td>0.61</td>
<td>0.56</td>
<td>0.21</td>
</tr>
<tr>
<td>Staple length</td>
<td>0.50</td>
<td>0.69</td>
<td>0.76</td>
<td>0.74</td>
</tr>
<tr>
<td>Crimps per inch</td>
<td>0.57</td>
<td>0.52</td>
<td>0.72</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Table: 6.1.11.
REPEATABILITY OF CHARACTERS FOR MEDIUM PEPPIN MERINO RAMS
(Heaton-Harris et al. 1969)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>REPEATABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight</td>
<td>0.84</td>
</tr>
<tr>
<td>Face cover score</td>
<td>0.71</td>
</tr>
<tr>
<td>Total folds score</td>
<td>0.68</td>
</tr>
<tr>
<td>Greasy fleece weight</td>
<td>0.78</td>
</tr>
<tr>
<td>Yield</td>
<td>0.71</td>
</tr>
<tr>
<td>Clean fleece weight</td>
<td>0.71</td>
</tr>
<tr>
<td>Staple length</td>
<td>0.62</td>
</tr>
<tr>
<td>Crimps per inch</td>
<td>0.76</td>
</tr>
<tr>
<td>Fibre diameter</td>
<td>0.83</td>
</tr>
</tbody>
</table>
Table: 6.1.12.
PRODUCTION TRAITS OF MERINO SHEEP: ACROSS COMPARISON MEANS, COEFFICIENTS OF VARIATION AND ESTIMATED REPEATABILITIES (Atkins et al. 1992)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>MEAN</th>
<th>COEFFICIENT OF VARIATION (%)</th>
<th>REPEATABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greasy fleece weight</td>
<td>6.4</td>
<td>10.5</td>
<td>0.66</td>
</tr>
<tr>
<td>Clean scoured yield</td>
<td>73.0</td>
<td>5.4</td>
<td>0.62</td>
</tr>
<tr>
<td>Fibre diameter</td>
<td>22.2</td>
<td>6.9</td>
<td>0.76</td>
</tr>
<tr>
<td>Clean fleece weight</td>
<td>4.7</td>
<td>11.6</td>
<td>0.62</td>
</tr>
<tr>
<td>Body weight</td>
<td>54.3</td>
<td>9.0</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Table: 6.1.13.
REPEATABILITY ESTIMATES OF MEDIUM WOOL MERINO RAMS 10 MONTHS Vs 18 MONTHS (Rogan et al. 1995)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>UNSHORN</th>
<th>SHORN AT WEANING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greasy fleece weight</td>
<td>0.26</td>
<td>0.52</td>
</tr>
<tr>
<td>Yield</td>
<td>0.59</td>
<td>0.62</td>
</tr>
<tr>
<td>Fibre diameter</td>
<td>0.68</td>
<td>0.69</td>
</tr>
<tr>
<td>Body weight</td>
<td>0.88</td>
<td>0.87</td>
</tr>
</tbody>
</table>
Table: 6.1.4.
PHENOTYPIC CORRELATIONS IN SOUTH AUSTRALIAN MERINO SHEEP
10 MONTHS Vs 16 MONTHS
(Ponzoni et al. 1995a)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>PHENOTYPIC CORRELATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greasy fleece weight</td>
<td>0.55</td>
</tr>
<tr>
<td>Yield</td>
<td>0.56</td>
</tr>
<tr>
<td>Clean fleece weight</td>
<td>0.55</td>
</tr>
<tr>
<td>Fibre diameter</td>
<td>0.72</td>
</tr>
<tr>
<td>Standard deviation of F.D.</td>
<td>0.57</td>
</tr>
<tr>
<td>Coefficient of variation of F.D.</td>
<td>0.62</td>
</tr>
<tr>
<td>Crimp frequency</td>
<td>0.50</td>
</tr>
<tr>
<td>Staple length</td>
<td>0.61</td>
</tr>
<tr>
<td>Staple strength</td>
<td>0.23</td>
</tr>
<tr>
<td>Dust penetration, back</td>
<td>0.14</td>
</tr>
<tr>
<td>Dust penetration, mid-side</td>
<td>0.17</td>
</tr>
<tr>
<td>Live weight</td>
<td>0.78</td>
</tr>
<tr>
<td>Scrotal circumference</td>
<td>0.58</td>
</tr>
</tbody>
</table>
6.2 APPENDIX: 2.

REPEATABILITY ESTIMATES OF OTHER WOOL & BODY CHARACTERS
Table: 6.2.1.
REPEATABILITY ESTIMATES FOR WRINKLE SCORE

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>REPEATABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young et al. (1960)</td>
<td>0.48 - 0.61</td>
</tr>
<tr>
<td>Beattie (1961)</td>
<td>0.62</td>
</tr>
<tr>
<td>Heaton-Harris et al. (1969)</td>
<td>0.68</td>
</tr>
<tr>
<td>Turner (1977)</td>
<td>0.50 - 0.70</td>
</tr>
</tbody>
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Table: 6.2.2.
REPEATABILITY ESTIMATES FOR FACE COVER

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>REPEATABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young et al. (1960)</td>
<td>0.36 - 0.49</td>
</tr>
<tr>
<td>Heaton-Harris et al. (1969)</td>
<td>0.71</td>
</tr>
<tr>
<td>Turner (1977)</td>
<td>0.40 - 0.50</td>
</tr>
</tbody>
</table>

Table: 6.2.3.
REPEATABILITY ESTIMATES FOR STAPLE STRENGTH

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>REPEATABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young et al. (1960)</td>
<td>0.58 - 0.72</td>
</tr>
<tr>
<td>Beattie (1961)</td>
<td>0.57</td>
</tr>
<tr>
<td>Heaton-Harris et al. (1969)</td>
<td>0.62</td>
</tr>
<tr>
<td>Mullaney et al. (1970)</td>
<td>0.57</td>
</tr>
<tr>
<td>Turner (1977)</td>
<td>0.50 - 0.70</td>
</tr>
</tbody>
</table>
### Table: 6.2.4.
REPEATABILITY ESTIMATES FOR CRIMPS PER INCH

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>REPEATABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young et al. (1960)</td>
<td>0.55 - 0.61</td>
</tr>
<tr>
<td>Beattie (1961)</td>
<td>0.71</td>
</tr>
<tr>
<td>Heaton-Harris et al. (1969)</td>
<td>0.76</td>
</tr>
<tr>
<td>Mullaney et al. (1970)</td>
<td>0.41</td>
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<tr>
<td>Turner (1977)</td>
<td>0.30 - 0.60</td>
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</tbody>
</table>

### Table: 6.2.5.
REPEATABILITY ESTIMATES FOR YIELD

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>REPEATABILITY</th>
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</thead>
<tbody>
<tr>
<td>Young et al. (1960)</td>
<td>0.54 - 0.66</td>
</tr>
<tr>
<td>Beattie (1961)</td>
<td>0.65</td>
</tr>
<tr>
<td>Heaton-Harris et al. (1969)</td>
<td>0.71</td>
</tr>
<tr>
<td>Mullaney et al. (1970)</td>
<td>0.78</td>
</tr>
<tr>
<td>Turner (1977)</td>
<td>0.50 - 0.80</td>
</tr>
<tr>
<td>Wade et al. (1992)</td>
<td>0.77</td>
</tr>
<tr>
<td>Atkins et al. (1992)</td>
<td>0.62</td>
</tr>
</tbody>
</table>
6.3 APPENDIX: 3.

REPEATABILITY ESTIMATES

OF

FERTILITY CHARACTERS IN MERINO EWES
Table 6.3.1.
REPEATABILITY ESTIMATES OF FERTILITY CHARACTERS IN MEDIUM PEPPIN EWES
(Young et al. 1963)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>EWE AGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 years old</td>
</tr>
<tr>
<td>Lambs born</td>
<td>0.09 ± 0.02</td>
</tr>
<tr>
<td>Lambs weaned</td>
<td>0.08 ± 0.01</td>
</tr>
</tbody>
</table>

Table 6.3.2.
REPEATABILITY ESTIMATES OF FERTILITY CHARACTERS IN MERINO EWES
(Turner 1977)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>REPEATABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lambs born/ewe mated</td>
<td>0.1</td>
</tr>
<tr>
<td>Lambs weaned/ewe mated</td>
<td>0.0 - 0.1</td>
</tr>
</tbody>
</table>

Table 6.3.3.
REPEATABILITY ESTIMATES OF FERTILITY CHARACTERS IN MERINO EWES
(Purvis et al. 1987)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>REPEATABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ewe fertility</td>
<td>0.05 - 0.17</td>
</tr>
<tr>
<td>Ewe reproduction rate</td>
<td>0.04 - 0.14</td>
</tr>
</tbody>
</table>

Table 6.3.4.
REPEATABILITY ESTIMATES FOR MERINO FLOCKS LAMBS BORN PER EWE LAMING
(Land et al 1983)

<table>
<thead>
<tr>
<th>BREED</th>
<th>REPEATABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australian Merino</td>
<td>0.15</td>
</tr>
<tr>
<td>Australian Merino</td>
<td>0.19</td>
</tr>
</tbody>
</table>

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6.4 APPENDIX: 4.

PHENOTYPIC CORRELATIONS BETWEEN
WOOL & BODY CHARACTERS
Table: 6.4.1.
PHENOTYPIC CORRELATIONS BETWEEN CHARACTERS IN SOUTH AUSTRALIAN MERINO RAMS AT 10 AND 16 MONTHS
(Ponzoni et al. 1995b)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>G.F.W. 10 months</th>
<th>C.F.W. 10 months</th>
<th>F.D. 10 months</th>
<th>B.W. 10 months</th>
<th>C.F.W. 16 months</th>
<th>F.D. 16 months</th>
<th>B.W. 16 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>G.F.W. 10 months</td>
<td>0.88</td>
<td>0.20</td>
<td>0.36</td>
<td>0.51</td>
<td>0.10</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>C.F.W. 10 months</td>
<td></td>
<td>0.18</td>
<td>0.32</td>
<td>0.55</td>
<td>0.11</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>F.D. 10 months</td>
<td></td>
<td></td>
<td>0.26</td>
<td>0.17</td>
<td>0.72</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>B.W. 10 months</td>
<td></td>
<td></td>
<td></td>
<td>0.33</td>
<td>0.23</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>C.F.W. 16 months</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.35</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>F.D. 16 months</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.27</td>
<td></td>
</tr>
</tbody>
</table>

Table: 6.4.2.
PHENOTYPIC CORRELATIONS FOR FINE AND MEDIUM WOOL MERINOS
(Skerritt et al. 1997)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>Average fibre diameter</th>
<th>Clean fleece weight</th>
<th>Hogget body weight</th>
<th>Staple length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av. fibre diameter</td>
<td>0.28</td>
<td>0.44</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>Clean fleece wt.</td>
<td></td>
<td>0.57</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>Hgt. Body wt.</td>
<td></td>
<td></td>
<td>0.43</td>
<td></td>
</tr>
</tbody>
</table>

Table: 6.4.3.
TRAIT MEANS, PHENOTYPIC VARIANCE AND PHENOTYPIC CORRELATIONS FOR FINE WOOL MERINO SHEEP
(Purvis and Swan 1997)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>Clean fleece weight</th>
<th>Mean fibre diameter</th>
<th>Coefficient of variation - fibre diameter</th>
<th>Staple length</th>
<th>Body weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.63</td>
<td>16.9</td>
<td>17.6</td>
<td>66.5</td>
<td>26.0</td>
</tr>
<tr>
<td>Phenotypic variance</td>
<td>0.06</td>
<td>1.13</td>
<td>4.99</td>
<td>0.80</td>
<td>9.95</td>
</tr>
<tr>
<td>Clean fleece weight</td>
<td></td>
<td>0.20</td>
<td>-0.10</td>
<td>0.34</td>
<td>0.44</td>
</tr>
<tr>
<td>Mean fibre diameter</td>
<td></td>
<td></td>
<td>-0.10</td>
<td>0.16</td>
<td>0.22</td>
</tr>
<tr>
<td>CoV fibre diameter</td>
<td></td>
<td></td>
<td>-0.12</td>
<td>-0.12</td>
<td>-0.19</td>
</tr>
</tbody>
</table>
Table: 6.4.4.
CHARACTER MEAN, STANDARD DEVIATION AND PHENOTYPIC CORRELATION IN FINE, MEDIUM AND BROAD WOOL MERINOS
(Brash et al. 1997)

| CHARACTER MEAN, STANDARD DEVIATION AND PHENOTYPIC CORRELATION IN FINE, MEDIUM AND BROAD WOOL MERINOS (Brash et al. 1997) |
|---|---|---|---|---|---|---|---|---|---|
| | 10 m. G.F.W. | 10 m. C.F.W. | 10 m. F.D. | 10 m. CofV | 10 m. B.W. | 10 m. Yld | 16 m. G.F.W. | 16 m. C.F.W. | 16 m. F.D. | 16 m. CofV | 16 m. B.W. | 16 m. Yld |
| Mean | 3.37 | 2.19 | 20.1 | 19.8 | 46.2 | 64.2 | 5.00 | 3.35 | 22.7 | 19.5 | 61.3 | 67.0 |
| Standard Deviation | 0.73 | 0.59 | 1.70 | 2.40 | 7.50 | 7.00 | 0.90 | 0.64 | 2.30 | 2.30 | 8.4 | 5.20 |
| 0 month G.F.W. | -0.01 | -0.17 | -0.09 | -0.40 | -0.14 | -0.54 | -0.48 | -0.12 | -0.01 | -0.33 | -0.00 | 0.03 |
| 0 month C.F.W. | 0.07 | 0.35 | 0.32 | 0.48 | 0.54 | 0.11 | -0.02 | -0.27 | 0.23 | -0.03 | -0.03 | 0.03 |
| 0 month F.D. | -0.04 | -0.26 | -0.03 | -0.21 | -0.16 | -0.77 | -0.03 | -0.20 | -0.04 | 0.03 | -0.03 | 0.03 |
| 0 month CofV | -0.09 | -0.03 | -0.18 | -0.15 | -0.02 | 0.06 | -0.10 | -0.01 | -0.03 | -0.03 | 0.03 | -0.03 |
| 10 month B.W. | -0.05 | -0.23 | -0.22 | 0.13 | -0.12 | 0.72 | -0.02 | -0.03 | 0.03 | -0.03 | -0.03 | 0.03 |
| 10 month Yld | -0.02 | -0.21 | -0.01 | -0.02 | -0.08 | -0.40 | -0.02 | -0.03 | -0.03 | -0.03 | -0.03 | -0.03 |
| 16 month G.F.W. | 0.84 | 0.22 | 0.12 | 0.28 | -0.06 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| 16 month C.F.W. | 0.15 | 0.07 | 0.24 | 0.48 | -0.03 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| 16 month F.D. | -0.01 | -0.12 | -0.10 | -0.10 | -0.03 | -0.03 | -0.03 | -0.03 | -0.03 | -0.03 | -0.03 | -0.03 |
| 16 month CofV | 0.13 | -0.04 | -0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| 16 month B.W. | -0.00 | -0.03 | -0.03 | -0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |

Table: 6.4.5.
PHENOTYPIC STANDARD DEVIATIONS AND PHENOTYPIC CORRELATIONS FOR SOUTH AUSTRALIAN MERINO SHEEP
(Hynd et al. 1997)

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>yearling C.F.W.</th>
<th>yearling F.D.</th>
<th>yearling CofV F.D.</th>
<th>hogget C.F.W.</th>
<th>hogget F.D.</th>
<th>hogget CofV F.D.</th>
<th>adult C.F.W.</th>
<th>adult F.D.</th>
<th>adult CofV F.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenotypic Standard Deviation</td>
<td>15.0</td>
<td>2.4</td>
<td>15.0</td>
<td>2.4</td>
<td>16.0</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>yearling C.F.W.</td>
<td>0.25</td>
<td>0.00</td>
<td>0.65</td>
<td>0.15</td>
<td>0.60</td>
<td>0.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>yearling F.D.</td>
<td>-0.19</td>
<td>0.15</td>
<td>0.70</td>
<td>-0.10</td>
<td>-0.10</td>
<td>-0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>yearling CofV F.D.</td>
<td>-0.00</td>
<td>0.10</td>
<td>0.50</td>
<td>-0.10</td>
<td>-0.10</td>
<td>-0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hogget C.F.W.</td>
<td>0.25</td>
<td>0.00</td>
<td>0.60</td>
<td>0.20</td>
<td>0.60</td>
<td>0.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hogget F.D.</td>
<td>-0.10</td>
<td>0.20</td>
<td>0.60</td>
<td>-0.10</td>
<td>-0.10</td>
<td>-0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hogget CofV F.D.</td>
<td>-0.00</td>
<td>0.10</td>
<td>0.50</td>
<td>-0.10</td>
<td>-0.10</td>
<td>-0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>adult C.F.W.</td>
<td>0.25</td>
<td>0.00</td>
<td>0.60</td>
<td>0.20</td>
<td>0.60</td>
<td>0.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>adult F.D.</td>
<td>-0.10</td>
<td>0.20</td>
<td>0.60</td>
<td>-0.10</td>
<td>-0.10</td>
<td>-0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>adult CofV F.D.</td>
<td>-0.00</td>
<td>0.10</td>
<td>0.50</td>
<td>-0.10</td>
<td>-0.10</td>
<td>-0.10</td>
<td></td>
<td></td>
<td></td>
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</tbody>
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7. REFERENCES:


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